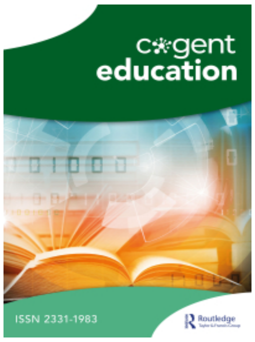

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The impact of gamification on achievement in mathematics among primary school pupils with hearing impairment

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ABSTRACT

Primary school pupils with hearing impairment face various obstacles to their academic and personal growth. The main aim of the study was to reveal the impact of the use of gamification methods on the mathematic achievement of primary school pupils with hearing impairment. This study used a pretest/posttest experimental strategy. The experiment was carried out in three stages. During the first stage, all participants' mathematical achievement level was measured and their mathematical progress was monitored. In the second stage, three game methods were applied to the experimental group consistently, according to pre-prepared lesson plans. The content of games methods was developed considering the topics, goals and expected results of the lessons. In the third stage, the impact of the game methods on first grade primary school hearing impaired pupils' achievement was assessed. Findings identified significant changes in the achievements of the experimental group. The implementation of gamification methods in mathematics lessons for first grade primary school pupils with hearing impairment resulted in a statistically significant improvement in the pupils' knowledge of numbers, calculations, geometry, measurements, and measurement, as well as in the level of higher-order thinking skills, knowledge, and understanding, i.e., from satisfactory to basic and advanced levels in the experimental group.

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Introduction

Mathematics in primary education develops competencies necessary to understand the basic concepts of mathematics in the general sense. It develops pupils' abilities to apply these concepts in everyday life and other areas, to logically explain their thoughts, to use mathematical concepts and to make predictions (Doğan, 2021). Primary school pupils with hearing impairment face many obstacles to their academic and personal growth. In this paper, the terms 'hearing impairment' or 'hearing loss' are used interchangeably in referring to a range of any decline in hearing capacity, including hardiness of hearing and deafness (World Health Organization, 2021). Hearing impairment is a person's inability to hear any sound, or the ability to hear sounds only of a certain sound frequency (decibels), and receive and understand information through the sense of hearing (Husniati et al., 2020; Saman et al., 2019). Hearing impairments are categorized into four levels ranging from mild to profound. The term 'hard of hearing' refers to a person who has residual hearing, and using hearing aids enhances hearing abilities and helps in successfully processing auditory information. This group also includes children with unilateral hearing loss (i.e. in only one ear). All of these children may experience similar learning difficulties (LeClair & Saunders, 2019). Because of these characteristics, the age of diagnosis or the use of cochlear implants, on the one hand, and the behavioural and educational beliefs of parents, including communication style

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and the ability to use sign language, on the other, children with hearing impairment are not a homogeneous population (Santos & Cordes, 2022). In addition, the changed medical, educational and social context of deafness calls for the validation of previous research results in a new context of early diagnosis of hearing impairment (aided by new medical technologies) and advances in early medical, educational and social services, enabling more effective correction of the primary disorder and prevention of secondary disorders due to hearing impairment (Grigonis & Narkevičienė, 2005).

Children with hearing impairment have visual, spatial and perceptual deficits (Pagliaro & Kritzer, 2013), resulting in delays in reading, writing and social development. They have low scores on assessments such as problem solving, logical thinking and reasoning (Topal et al., 2017). The results of many studies reveal that the achievement of students with hearing impairment is much lower than that of their hearing peers (Hoffmeister et al., 2021; Szucs, 2020). Children with hearing impairments have been found to have delays in abstract numeracy (counting without concrete tools) and in understanding the principles of counting, and to perform slower in standardized mathematics achievement tests that require more than just arithmetic operations (Gottardis et al., 2011). Students with hearing impairment lag behind in mathematics achievement by an average of two to four school years (Szucs, 2020). What's more, as analyses of more than 30 years of data from the Stanford Achievement Test (SAT) in mathematics show, the maths underachievement gap of children with hearing impairment identified in childhood spans a wide range of domains and persists into adulthood (Qi & Mitchell, 2012; Santos & Cordes, 2022).

Research shows that hearing impairment is not the only cause of poor academic performance in mathematics, and it seems necessary to think about the educational environment (Barbosa, 2014). It has been observed that children learning singular, dual and plural linguistic forms, as is the case in Lithuanian, benefit from more extensive grammatical number marking (Sarnecka, 2014). In mathematics language learning, both sign and spoken language use linguistic devices (e.g. reduplication) to encode aspects of number, such as plurality and size – for example, words and phrases such as 'more' or 'inside' or 'next to' (Kurz & Pagliaro, 2019; Purpura et al., 2017). Such evidence also suggests that language has an impact on mathematical ability early in development, but other factors, such as the direction of education, may increase these mathematical difficulties as children with hearing impairments get older (Santos & Cordes, 2022). In our study, pupils with hearing impairment are children whose native language, through which they receive information, acquire knowledge and learn about the world, is Lithuanian sign language.

When analysing the academic achievements of pupils with hearing impairment who study in Lithuanian specialized centres for the education of the deaf and hard of hearing, very low mathematics achievement results are observed. According to the Lithuanian National Education Agency, the results of the 2022 Basic Education Achievement Test showed that the mathematics achievement of hearing-impaired pupils was only 4.1 on average (NSA, 2022a). Their relationship with the written text of the Lithuanian language is very weak, especially for students who study in primary education. As a result, pupils are unable to read task instructions or understand oral task conditions, which may negatively impact their further education and achievements.

With these disadvantages, children learning mathematics require adapted educational services. It is particularly important to provide hearing-impaired children with a wide range of early educational support and mathematical learning that take into consideration the specific characteristics and requests of these pupils (Edwards et al., 2013; Langdon et al., 2023; Santos & Cordes, 2022). Research into the use of gamification in mathematics learning for pupils with hearing impairment has explored various aspects. In the search for opportunities to improve learning outcomes and motivation in mathematics education, research has focused on the effects of different gamification techniques on learning in the affective, cognitive and psychomotor domains (Kaimara et al., 2021; Yan et al., 2023). The use of video games, when complemented by the support of another person, such as a human tutor, has been found to be a promising way to improve the mathematics learning experience of pupils with special educational needs, including those with hearing impairments (Karunamoorthy & Tahar, 2020; Malvasi et al., 2022; Marcelino et al., 2022; Triantafyllou 2022). Hearing-impaired students enjoy improved mathematics achievement due to enhancements in cognitive function, problem-solving skills and overall engagement with the learning process. However, research on the development of mathematical concepts and the mathematical achievement of primary school pupils with hearing impairments is still scarce

(Langdon et al., 2023); moreover, such studies rarely analyse the impact of gamification methods on such pupils.

Therefore, the research questions were formulated as follows: what are the learning needs and difficulties in mathematics of primary school pupils with hearing impairments? What are the mathematics achievements of pupils with hearing impairments? How does the use of gamification in the classroom contribute to the mathematics achievement of primary school pupils with hearing impairment?

The aim of the research to reveal the impact of the use of gamification methods on the mathematics achievements of primary school pupils with hearing impairment.

To meet our purposes, we have structured the article into three sections. In the first section, we review the theoretical background of gamification in mathematics learning for pupils with hearing impairments and the state of the research, and present our research questions. In the second section, we present an innovative gamification-based educational intervention for primary school pupils with hearing impairments, and the methods used for data collection and analysis. Third, we present and discuss the results of our analysis.

Literature review

Achievements and difficulties of hearing-impaired pupils in learning mathematics

Mathematical cognition is not uniform (Levine & Baillargeon, 2016). The mathematics achievement of hearing-impaired pupils in primary school is influenced by a variety of factors: pupils' general cognitive abilities, motivation, self-confidence, the pupils' environment and innovative teaching methods. For example, general cognitive ability determines processing speed (Chan et al., 2022; Chen & Wang, 2021). But one of the main reasons is the language differences in how children with hearing impairments receive, perceive and store information: through gestures that have minimal connection to spoken and written language (Krause & Wille, 2021; Santos & Cordes, 2022).

Therefore, the main learning difficulties experienced by children with hearing impairment are briefly reviewed under the following themes: mathematical cognition, mathematical communication, algebraic thinking, counting, logical-mathematical thinking and numeracy. Mathematical understanding – the construction of mathematical concepts – according to Piaget and many other scientists who followed him (Piaget, 1953), does not only take place when children are already able to operate the abstract symbols that characterize formal education, but on the contrary begins before formal education and is initially characterized by mental representations that involve the existence of concrete entities and the transformations of those entities. In other words, it is assumed that mathematical cognition is in principle informal because it operates on cognitive objects that are not symbolic or formal but require experience of the physical world (Piaget, 1953). This means that children with hearing impairments have certain mathematical communication skills, which may enable them to understand concepts and support them in solving problems by linking mathematical concepts to other disciplines (Leton et al., 2019). However, the limited access to information for children with hearing impairments affects their efforts to improve their mathematical communication skills, as children do not use their full cognitive potential when processing information due to communication and problem-solving limitations. Children with hearing impairment and reduced language development experience lower mathematics achievement in, for example, counting (Nunes & Moreno, 1998, 2002; Topal et al., 2017), word problems (Hyde et al., 2003), fractions (Titus, 1995) and arithmetic comparison problems (Kelly & Mousley, 2001). Language contributes to number cognition (Kurz & Pagliaro, 2019). Secada (1984) found this to be the case when comparing deaf children, who learn sign language from birth, with normally hearing children, who learn spoken English, with both groups showing a similar development of rote counting skills (i.e. both groups are able to reproduce number words consecutively, without understanding their quantitative meaning).

Barbosa's (2014) study showed a clear difference between mathematical cognitive skills that are more or less dependent on linguistic stimuli, noting that children with hearing impairments achieve at the same level as hearing children and, in some cases, even better than hearing children when their skills are less dependent on linguistic stimuli.

Using a longitudinal study design (Gottardis, 2016), it was observed how factors related to children with hearing impairment (degree of hearing loss, age, years of schooling, presence of a cochlear implant, gender and causes of deafness) and environmental factors (mother's highest level of education, the language spoken at home and type of educational institution) can predict the potential delay in mathematics learning. Logical-mathematical reasoning, working memory and numeracy skills were chosen as predictors of mathematical achievement when analysing the difficulties of children with hearing impairment compared to their hearing peers. Hierarchical regression analysis showed that numeracy and working memory independently contributed to the prediction of children's mathematical achievement, but logical mathematical reasoning was the strongest predictor. Thus, age, years of schooling delay and type of educational institution were found to be moderators of the degree of mathematical achievement. Second, the likelihood of a causal relationship between the logical-mathematical thinking, numeracy, working memory and mathematical achievement of children with hearing impairment was established. This implies that schools need to explicitly plan for the development of children's mathematical reasoning, numeracy and working memory in kindergarten and in the first year of school (Gottardis, 2016).

For children with hearing impairments, Bull et al. (2018) also found that approximate number system acuity (non-symbolic magnitude processing) was significantly associated with mathematics performance, and higher approximate number system acuity was correlated with better performance in both the numerical operations and mathematical reasoning subtests. Furthermore, children with hearing impairments had less acuity in the approximate number system than their hearing peers, which may be the reason why the mathematics achievement of hearing-impaired children lags behind. Students with hearing impairments face unique challenges in the construction of algebraic thinking, especially in the topic of algebra units (Leton, 2022).

Educational needs of primary school pupils with hearing impairment

As the literature reviews show, over the last 20 years, there has been clear evidence that the linguistic experiences of children with hearing impairment and their impact on children's numeracy skills in preschool and primary school affect later academic outcomes (Langdon et al., 2023). From early childhood onwards, individual differences in mathematics achievement are primarily determined by the characteristics of parents, as suggested in the review by Elliott and Bachman (2018), namely the way they talk about mathematics, the mathematical activities they engage in and the attitudes they have towards mathematical concepts.

The most important symbol of the Deaf culture and its members is the sign language because it shows the identity of this group and its relationship with other groups in society. Although sign language is the mother tongue of hearing-impaired people, 90% of hearing-impaired children are born into hearing families (Mitchell & Karchmer, 2004). Parents' main goal is to prepare their child to integrate into the hearing society by using technical means of hearing rehabilitation (hearing aids or cochlear implants). Even if hearing cannot be restored to minimal normality, many parents still prioritize spoken language over sign language. As stated by some researchers (Chan et al., 2022; Henner et al., 2021; Saman et al., 2019), when parents choose to communicate with their children verbally instead of through sign language, or hearing parents do not know sign language expertly, they underestimate children's challenges. Such children face a lack of a linguistic environment, along with communication and learning problems, and do not know their first, native (sign) language well, and without the first language, learning a second (oral) language and understanding its written form is even more difficult.

According to Hoffmeister et al. (2021), children learn language indirectly and procedurally. First, they understand the communicative context specific to the situation, and then they transfer their understanding of linguistic meaning to words and phrases. It is noted that hearing-impaired students must first be proficient users of their native language in order to be able to apply various techniques to navigate the printed text. Only those students who have a very good foundation in their native language have a developed conceptual knowledge that will allow them to encode words according to certain correspondences, look for similarities and apply various strategies for reading and understanding words (Chan et al., 2022). This native language proficiency contributes to the development of mathematical vocabulary and conceptual language, which significantly improves numeracy skills, and students exposed to sign language at home performed significantly better in a maths test (Henner et al., 2021). It has been observed that students who have grown up with sign language are perfectly able to observe the visual material of the lesson presented in slides or textbooks and at the same time observe the teacher who explains the content of the lesson in sign language. Students with hearing impairment who are proficient users of sign language have been found to have higher reading, writing and numeracy skills (Scott, 2022). In contrast, those hearing-impaired students who did not use sign language at home did not have the skills to follow both the visual materials of the lesson and the teacher (Saman et al., 2019).

It is not effective to focus only on vocabulary development and reading skills to improve mathematical achievement: abstract thinking skills, which are developed through the use of the mother tongue, are also very important (Pagliaro & Thom, 2021).

According to the study by Pagliaro and Thom (2021), robust, interactive behaviour helps to form the higher-level thinking skills needed to ask questions, to be able to express one's thoughts, and to understand and relate one's experiences to certain concepts and their meanings. Students with these abilities have more opportunities to become involved in mathematics and achieve higher results (Husniati et al., 2020).

Hearing-impaired pupils form their thinking and learn using visual memory. The dominance of visual memory is influenced by the sign language used to think, communicate, receive and process information. To be successful in mathematics one must engage in higher cognitive levels of knowledge, just as in the case of language learning. Moreover, mathematics and language skills assist each other in creating a mutual relationship that allows the learner to learn both language and mathematics at the same time. In senior grades, mathematical thinking develops higher mathematical abilities and the application of functions (organization, problem solving, formulating conclusions, reasoning) in science and real life, which also requires higher linguistic abilities. That is why teaching oral language to students with hearing impairment is inseparable from teaching mathematics (Husniati et al., 2020). The current metanalysis (McFayden et al., 2023) results show that, in the usual assessment of working memory in educational and cognitive contexts, the inherent hearing bias in the use of verbal items, such as numerals, can underestimate the abilities of Deaf sign language learners. Although previous literature has suggested that Deaf sign language users have weaker short-term and working memory for serial recall items, McFayden et al. (2023) point out that Deaf sign language users are able to recall visual items in serial order when they are presented in front of them, similarly to hearing non-sign language users. Thus, hearing-impaired students can perform as well as, or better than, their hearing peers in mathematics tasks when the tasks are presented with an emphasis on the use of non-verbal, visual and spatial skills rather than language (Marschark et al., 2017).

Teaching spoken language to hearing-impaired children, especially deaf children, should be treated as learning a second language, and methods and tools of second-language learning should be applied (Chan et al., 2022). That is why it is necessary to develop a methodological technique that would teach children with hearing impairment to navigate a printed text and be able to decode it with gestures (Chan et al., 2022; Edwards et al., 2013). As stated by Shelton and Parlin (2016), conditions, comparisons, negations and inferences are often used in mathematics, so communication, language skills and the ability to read and understand a written text are very important for the successful achievement of learning outcomes.

Attempts have been made to discover the causality of the low academic achievements of students with hearing impairment, especially deaf students, over several decades. The descriptions of mathematics learning trajectories help teachers to anticipate relevant areas of progress, but in order to understand the level of proficiency, it is important to refer to the strategies for formative assessment of achievement (Pagliaro, 2015), which comprise three levels: concrete, representational or pictorial, and abstract or symbolic. As stated by Pagliaro and Thom (2021), mathematical concepts are not memorized but constructed based on the principle that various schemes are combined into new, more complex mathematical concepts and procedures. Children must understand the lower-level, more specific concepts to understand higher-level, more abstract ones. With this statement, the authors justify why, in many cases, teachers working with hearing-impaired children assign them lower-level mathematical tasks. Learners cannot understand facts or abstract mathematical concepts and are not able to apply them correctly in various fields if they do not yet understand numbers and the relationships among numbers through active practical, meaningful activities. A teacher's inability to communicate in sign language has a negative impact on the understanding and solving of verbal and logical tasks because it has been noticed that teachers of pupils with hearing impairment focus on elementary exercises and arithmetic drills in the classroom, rather than problem solving requiring complex mathematical language (Easterbrooks & Stephenson, 2006). In Lithuania, almost a third of pedagogues working in educational institutions for the deaf do not know sign language or have very low sign language skills, which complicates the teaching process (NSA, 2022b). Analysing the reasons why mathematics achievement is low, Golstein (2018) suggests that inadequate teaching, low teacher expectations and students' learning difficulties due to low reading levels play a role. Hearing-impaired children come to school with a low language foundation, which is important for a smooth start to education, so teachers try to fill the gaps procedurally. It is often observed that teachers lack the knowledge and proper preparation to teach students with hearing impairment; they use traditional learning methods that are not effective for their special educational needs and often avoid teaching concepts or complex mathematical procedures that they consider too difficult for these students. Shelton and Parlin (2016) also mention in their work that the teaching of mathematics in special education institutions is mostly based on traditional learning activities, such as rote counting, subtraction and addition and performing simple procedures, with little emphasis on higher-level thinking skills and real problem solving. Educators arguing for such a choice raise the vocabulary problems of deaf students, which leads to the fact that these students are unable to understand the conditions, comparisons, negatives and conclusions – multi-meaning words that are often used in mathematics, which prevent these students from understanding the tasks and solving them correctly.

Husniati et al. (2020) argue that success in mathematics lessons can be ensured by considering several factors, including social and natural ones. While objective assessment of mathematical skills is an important measure, mathematical anxiety and children's subjective self-assessment are also important aspects (Ganley & Lubienski, 2016). Social factors show how a person can communicate with others and transfer information; natural factors are associated with the cooperation and integration of human senses (sight, hearing, smell, taste, touch). For people with severe hearing impairment or those who may not benefit from traditional language training, alternative communication methods can be effective. Research has focused on the impact of gamification techniques on students' learning in the affective, cognitive and psychomotor domains in order to improve learning outcomes and motivation in mathematics education (Yan et al., 2023). The purpose of sensory cooperation is to recognize and fully understand objects in the environment, just like problem solving in mathematics.

Mathematics achievement of hearing-impaired elementary students using gamification methods

Gamification is a learning approach whereby game elements are applied to non-game situations and environments (Deterding et al., 2011; Kim et al., 2018); it has been shown to be effective in enhancing children's learning outcomes and motivation, and in improving their learning experience (Busarello et al., 2016; Rodríguez-Ferrer et al., 2023), by increasing user engagement and the attractiveness of the learning process (Christopoulos & Mystakidis, 2023). According to Busarello et al. (2016), gamification is a system used to solve problems by increasing and maintaining the level of engagement by stimulating the intrinsic motivation of the individual, through the use of playful scenarios to model and explore phenomena with external objectives, and it is supported by the use and creation of play elements. While gamification is often aimed at creating and maintaining internal motivation, it also applies to external motivators (Richter et al., 2015). Gamification involves motivational strategies applied to a problem-solving situation, based on the general systemic concept of games and theories of storytelling. The main aim is to incorporate the full experience of individuals into the game, placing them in a fictional universe in order to facilitate and accelerate the generation and application of personal knowledge (Rodríguez-Ferrer et al., 2023). For example, Marinagi and Skourlas (2013) used a web-based game that integrates wireless connectivity with networks and mobile devices into educational scenarios. They observed increased interest in, and improved communication between, learners and teachers. Also, a study conducted by Gafni et al. (2018) on the impact of gamification elements on e-learning platforms revealed that students exposed to gamified e-learning platforms demonstrated high-achievement learning and were motivated to continue learning after the experience. These findings provide confidence in the effectiveness of gamification in the learning process.

Recognized for their entertainment value, gamification or serious games are promoted for their potential to shape game users' behaviour in a desirable direction; they serve to improve decision-making and a user's understanding of a particular phenomenon (Dichev et al., 2015). The use of games in an educational context is an innovative strategy aimed at helping to develop students' skills and abilities in interdisciplinary scenarios such as creativity, autonomy, responsibility, flexibility and collaboration (Pontes et al., 2020).

Most authors observe a close and rational connection between game methods and the content of mathematics lessons. Boudadi and Guitierrez (2020) see close links between gamification methods and the qualities needed to solve mathematical tasks. According to Karamert and Kuyumcu (2021), games are essentially mathematical and only mathematical ability allows people to win them. Rationality, creative thinking, inference formation and similar interactions are captured in both maths tasks and games.

Doğan (2021) states that in the context of elementary education, the objectives of mathematics lessons are very different and integrated. These objectives include: to develop a positive attitude towards mathematics; to instill self-confidence; to develop intellectual curiosity; to understand the historical development of mathematics and its role in the development of human thought; to conduct research; to develop the ability to create and use knowledge to establish the relationship between mathematics and art and aesthetic feelings. It is precisely for this reason that different methods, tools and strategies are needed to achieve these goals. Moreover, game design elements in gamified methods can make 'dry', boring subjects such as mathematics interesting for students (Kamalodeen et al., 2021). It has been established that pupils with hearing impairments benefit from gamification and experiential learning methods to improve their maths performance. El Mawas et al. (2019) identified how an interactive 3D educational video game can help primary school children with hearing impairment learn about the solar system. The first part of the game uses a game-based methodology for interactive learning, while the second part allows the exploration of an interactive, image-based digital library. Analysis of the pretest and posttest results showed that the game helped children develop their conceptual knowledge of the subject.

Looking for new opportunities to improve the mathematics achievement of hearing-impaired students, Shelton and Parlin (2016) found that an experiment in which interactive educational games were introduced into the mathematics education process demonstrated that new technologies and innovative educational methods create an attractive and motivating learning environment and system that helps hearing-impaired students to enhance their daily interest in learning, develop their creative thinking skills and improve their inductive reasoning skills and pupil-to-pupil communication. Learners may use games installed on tablets to solve puzzles or deepen existing knowledge about a certain topic, improve skills by interacting with others, propose solutions to problems encountered during problem-based learning scenario challenges and create statistical reports (Pontes et al., 2020). Therefore, a gamification approach is far from being limited to simple entertainment; it combines the domains of play and education and is also a practical and promising avenue for assisting pupils with hearing impairment (Kaimara et al., 2021). In the learning process, gamification should focus on exploring students' intrinsic motivation, otherwise the simple application of basic game mechanics to the process may lead to negative results. Through everyday situations, investment should be made in the student's curiosity, satisfaction and trust in the process (Busarello et al., 2016; Kamalodeen et al., 2021).

López et al. (2021) note that the application of the game method in mathematics is often misused and inappropriately described. In order to obtain effective results, it is very important to take into account the four main characteristics that maths game activities must have: 1) they must incorporate a given problem that needs to be solved individually or in cooperation with other learners in order to achieve the goals; 2) they must create challenges among users; 3) the results must be accounted for, and students must receive an award or prize; 4) levels and rankings must be created so students can get feedback, compete and compare their performance. The authors note that these indicators are closely related to the principles of mathematical education, which emphasize mathematical problem solving, reasoning, proof, collaboration, communication and representational processes, which are more closely related to thinking and acting than to memorizing concepts and repeating procedures. In addition, the use of video games, when complemented by a human tutor, has been found to be a promising approach for improving the mathematics achievement of students with special educational needs, including students with hearing impairments (Marcelino et al., 2022).

Research into the use of gamification in mathematics learning for students with hearing difficulties has explored various aspects. Overall, these studies highlight the importance of incorporating gamification elements to improve the mathematics learning experience for students with hearing impairments, with an emphasis on improving cognitive functions, problem-solving skills and overall engagement in the learning process.

Methods

Research design

Participants

All first-grade students with hearing impairment who were studying in Lithuanian deaf and hard-of-hearing education centres participated in the experiment. In 2022–2023, there were 13 pupils in the first grade in specialized deaf education institutions in Lithuania. Another criterion that was applied to the subjects was that students must have been studying according to the general education programme. Two pupils out of the selected 13 were following individualized education programmes; therefore, only 11 students participated in this study, and they were purposefully divided into experimental and control groups, according to the researcher. The experimental group (hereafter EG) was comprised of one first-grade class ($n = 6$, including 3 boys and 3 girls); the control group (hereafter CG) was comprised of one first-grade class ($n = 5$, including 3 boys and 2 girls). In the EG, one pupil was hard of hearing and had mild hearing loss, and five pupils had profound hearing loss (deafness). In the CG, two pupils were hard of hearing, with moderate hearing impairment, and three had profound impairment (deafness) (Figure 1).

Data collection processes and data analysis

The educational experiment was carried out in three stages. During the first stage, all participants' mathematical achievements were measured. To determine the level of mathematical achievements, a Mathematics Progress Monitoring Test (hereafter MPMT; Kliziene et al., 2021) was adapted for the pupils with hearing impairment. In the second stage, game methods were consistently applied to the experimental group (EG), according to pre-prepared lesson plans. The content of gamification methods was developed in light of the lessons' topics, goals and expected results. In the third stage, the impact of the game methods on pupil achievement was assessed. To assess progress, pupils completed the MPMT.

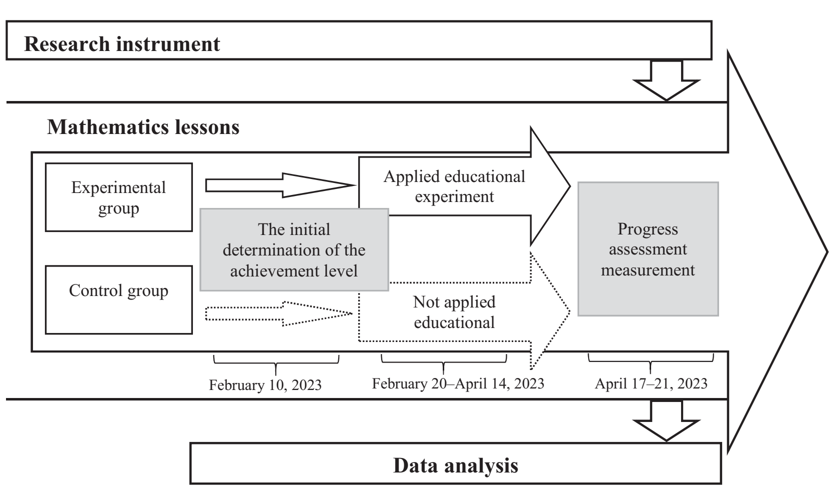

Figure 1. Logic diagram for the study.

Two MPMTs developed for the purpose of study were used to assess the progress in mathematics achievement of the pupils participating in this study. The General Curriculum Framework for Primary and Basic Education (2008) was taken into consideration in designing the tests. They were developed to assess each pupil's level of achievement, which, in accordance with general education programmes, was divided into unsatisfactory, satisfactory, basic and advanced.

The mathematical achievements of pupils with hearing impairment were evaluated according to the five areas of the mathematics education curriculum (General Curriculum Framework for Primary and Basic Education, 2008; Kliziene et al., 2021):

1. numbers and calculations (can read and write natural numbers up to 100, compare them, tell the composition of two-digit numbers from tens and ones, perform addition and subtraction, solve the simplest problems of real content);
2. phenomena, equations and inequalities (knows how to calculate the numerical values of the simplest phenomena or quantities, to rearrange simple numerical phenomena based on the laws of rearrangement of composition; to check whether the given equality is correct);
3. geometry, measures and measurements (able to recognize and properly name the simplest geometric planes and spatial figures; knows their names; applies existing knowledge about geometric planes and figures; able to solve simple problems);
4. statistics (understands how data is represented, knows how to collect it, read information presented in a column chart; is able to represent it in a chart based on the data presented in the condition);
5. communication and general problem-solving skills;

and cognitive ability groups: 1) mathematical knowledge (the pupil is able to understand concepts and perform standard mathematical procedures based on them); 2) understanding (the pupil is able to correctly understand the conditions of the tasks and, based on them, present the solution methods); 3) application of mathematics and higher thinking abilities (the pupil is able to solve more complicated procedure tasks, 'to which there are several possible strategies to solve them; the pupil himself/herself is able to choose the strategy and apply it to solve the problem correctly).

According to the matrix of the developed test, the content of the subject of mathematics, the cognitive ability groups and the pupil's achievement levels, the highest possible score was calculated for each research area – a result that was used to assess each pupil's achievements in a particular field indicated by the MPMT. To ensure equal evaluation of each pupil's MPMT results according to the fields of activity, MPMT evaluation instructions were used and the limits of pupils' achievement levels were defined based on the MPMT characteristics (unsatisfactory, satisfactory, basic, advanced).

As defined in the MPMT characteristics, the advanced level of achievement requires the pupil to accumulate 26–33 standard points from their MPMT tasks done during the research; the basic level – 12–25 standard points; the satisfactory level – 5–11 standard points; while the unsatisfactory level requires 0–4 standard points. Based on these levels of learning achievement, the impact of the process using gamification methods on pupils' mathematical achievements was assessed.

The level of pupils' achievement is a criterion for evaluating the organization of the learning process. This assessment was used to analyse, interpret and compare the links between students' ways of organizing learning and achievement. The four levels of achievement are described as follows. At the advanced level of achievement, the pupil has a perfect understanding of available knowledge and is able to apply it in various practical tasks and contexts and apply various strategies; the pupil is able to consistently and reasonably explain the sequence of problem solving; he/she uses concepts and terms correctly and performs practical maths tasks and procedures in various contexts without errors.

At the basic level of achievement: the pupil reproduces existing knowledge and applies it in a new context; correctly understands tasks in a simple context; does not make fundamental mistakes when solving them; is able to answer questions rationally, using appropriate concepts and terms, but sometimes lacks accuracy, consistency and coherence.

At the satisfactory level of achievement, the pupil's knowledge and understanding are superficial; they are able to recognize certain concepts, solve the simplest problems and perform standard mathematical procedures, choose methods and results for solving tasks but sometimes makes mistakes with them, and the final answer is incorrect.

At the unsatisfactory level of achievement, the pupil does not achieve the satisfactory level of achievement in any of the mathematical activity ability groups.

Gamification methods used for the research

This study aimed to measure the impact of game methods on the mathematics achievements of students with hearing impairment; therefore, three game methods were chosen at the beginning of the study, which were consistently applied in the EG mathematics lessons throughout the study. We implemented games 'with an educational bee', namely the robot 'Bee-bot', which is a tool for teaching the basics of programming, with seven basic control functions (forward arrow, backward arrow, left arrow, right arrow, OK button, which allows one to start executing a programmed command, button X for cancelling the command and button II for stopping the command). Different task boards and worksheets were created for each game based on the topics of that lesson. This game method in mathematics lessons has been used to develop different pupils' abilities in the areas of numbers and calculation and statistical activities. The peculiarity of this game is that the pupils have to predict and program the direction of the robot's movement toward the intended goal in advance.

The second game method was the interactive team game 'Bamboozle', where various types of tasks were presented. By designing game tasks, a system of points and time was foreseen in advance. The game allowed pupils' teams to choose one card with a question on the other side. With the program it was possible to present both written and visual content, which is relevant in terms of its informativeness to pupils with hearing impairment. This method aims to develop pupils' mathematical communication competences, including the purpose of explaining and paraphrasing mathematical information presented in various forms (text, picture, scheme, formula, table, drawing, graph, diagram). The text conditions of the tasks supplemented with meaningful illustrations were used as a learning tool to learn the text-reading strategy. In the team game aspect, pupils had the opportunity to learn by explaining to their teammate the problem statement and their understanding of it, what mathematical concepts and terms were used in the activity and what each of them meant, what solution each teammate came up with and how to justify their proposal with arguments, and to come up with a joint solution and answer.

The third game method – interactive escape room games – was created with 'genial.ly', which allows teacher to offer pupils multifunctional games by including tasks of various types (textual, test, puzzle type, strategic). One of the paper's authors created games and content, either by designing a game themselves or by redesigning a game based on templates provided. This platform was used to create interactive pictures and supplement textual information with interactive information by linking the written text of the Lithuanian language with the video information provided in the Lithuanian sign language dictionary. The game allowed the teacher to add new words and concepts unfamiliar to pupils who use Lithuanian sign language, thus adapting the textual information to the needs of hearing-impaired pupils and making it more comprehensible.

Research ethics

On 6 February 2023 the researchers received approval to conduct the investigation in accordance with protocol no. M4-2023-03. The heads of the educational institutions participating in the study and the parents of the participating students were informed about the purpose and course of the study. They were presented with the informed consent forms approved by the KTU Scientific Research Ethics Commission, in which all detailed information was included. The most important ethical principle of this study was to ensure the confidentiality of the participating pupils; therefore, no personal data of the students are presented in the study, and full pseudonymization of personal data is ensured.

Data analysis

Quantitative mathematical statistical methods were used to process the data collected in the study, which allowed the calculation of the arithmetic mean, standard deviation and the mean of the result, calculated based on the highest possible score. The Mann–Whitney *U* test is commonly used by researchers to compare two groups of non-parametric criteria for statistical hypotheses, and that is why it was used to process the results of this study. The following indicators were used for the reliability of conclusions: $p > 0.05$ – there is no statistically significant difference; $p < 0.05$ – the difference is statistically significant. Calculations were performed using Excel and SPSS programs (IBM SPSS Statistics (Version 29).

Results

Distribution of mathematical learning achievements according to curriculum content of primary school pupils with hearing impairments

Table 1 presents the results of the descriptive data of first-grade primary school pupils with hearing impairments by learning needs and difficulties in mathematics before and after gamification (pretest/posttest). We found that before the experiment (pretest), the results of the CG (8.40 (2.75)) and EG (10.58 (3.51)) were not statistically different. Using gamification (EG) for hearing-impaired pupils showed a statistically significant increase in numbers and calculations (EG pretest 10.58 (3.51), posttest 16.33 (1.97) ($p = 0.009$)), compared to the control group (pretest 8.40 (2.75), posttest 10.80 (3.27)). Comparing the EG data before and after intervention, we found a statistically significant difference ($p = 0.011$). *Phenomena*, *equations* and *inequalities*: pretest CG and EG ($p = 0.915$), posttest CG and EG ($p = 0.409$). *Geometry*, *measures* and *measurements*: established that pretest, the results of both the CG (0.00 (0.00)) and EG (1.67 (2.25)) were not statistically different ($p = 0.081$). Using gamification (EG) for hearing-impaired pupils showed a statistically significant increase in geometry, measures and measurements – EG pretest 1.67 (2.25), posttest 6.50 (1.38) ($p = 0.02$), compared to the control group (pretest 0.00 (0.00), posttest 3.80 (1.30). Comparing the EG data before and after gamification, we found a statistically significant difference ($p = 0.018$). *Statistics:* pretest CG and EG ($p = 0.689$), posttest CG and EG ($p = 0.057$). *Communication and general problem-solving skills:* pretest CG and EG ($p = 0.891$); posttest CG and EG ($p = 0.058$) (Table 1).

Distribution of mathematics learning achievement by areas of cognitive abilities of primary school students with hearing impairment

Table 2 presents the distribution of pupils with hearing impairment in the EG and CG groups at pretest and posttest by areas of cognitive ability. We found that for pretest results of knowledge and understanding, the CG (5.80 (2.28)) and EG (7.42 (1.32)) were not statistically different. Using gamification (EG) for pupils with hearing impairment showed a statistically significant increase in knowledge and understanding – EG pretest 7.42 (1.32), posttest 12.33 (1.03) ($p = 0.008$), compared to the control group (pretest 5.80 (2.28), posttest 8.40 (2.07)). It has been established that there is a statistically significant difference when comparing the EG data before and after gamification ($p = 0.024$). There was a statistically significant increase in higher thinking skills – EG pretest 0.33 (0.52), posttest 6.17 (1.47) ($p = 0.012$), compared to the control group (pretest 0.20 (0.45), posttest 6.60 (1.67)). Comparing the EG data before and after gamification, we found a statistically significant difference ($p = 0.009$).

Levels of mathematics achievements of pupils with hearing impairments

An analysis of the results of the MPMT pretest found that before the experiment (pretest), the results of the CG satisfactory level (6.00 (2.40) and EG (8.08 (1.72)), basic-level results for the CG (6.00 (2.58) and EG (6.83 (3.06), and advanced level results for the CG (0.20 (0.45) and EG (0.50 (0.84)) were not statistically different (Table 3). As can be seen from the results, gamification methods in mathematics lessons helped pupils with hearing impairment to achieve basic results (posttest CG 11.00; EG 19.00; $p = 0.013$) and

Table 1. Distribution of mathematics learning achievement by content of primary school students with hearing impairment (pretest and posttest results).

						Control group			Experimental group		
Test	Control group	Experimental group	*p*-level	Observed power	Effect size	*p*-level	Observed power	Effect size	*p*-level	Observed power	Effect size
Pretest											
Numbers and calculations	8.40 ± 2.75	10.58 ± 3.51	0.313	0.194	–	–	–	–	–	–	–
Phenomena, equations, inequalities	3.00 ± 1.41	2.83 ± 1.83	0.915	0.024	–	–	–	–	–	–	–
Geometry, measures and measurements	0.00 ± 0.00	1.67 ± 2.25	0.081	0.588	–	–	–	–	–	–	–
Statistics	1.00 ± 0.71	0.83 ± 0.98	0.698	0.239	–	–	–	–	–	–	–
Communication and general problem-solving skills	0.20 ± 0.45	0.17 ± 0.41	0.891	0.095	–	–	–	–	–	–	–
Posttest											
Numbers and calculations	10.80 ± 3.27	16.33 ± 1.97	**0.009**	1.000	0.81	**0.049**	0.816	0.51	**0.011**	1.000	0.92
Phenomena, equations, inequalities	0.60 ± 0.55	0.83 ± 0.41	0.409	0.107	–	**0.014**	0.926	0.71	**0.048**	0.795	0.81
Geometry, measures and measurements	3.80 ± 1.30	6.50 ± 1.38	**0.020**	0.983	0.28	**0.000**	1.000	0.97	**0.018**	0.957	0.95
Statistics	0.80 ± 1.30	2.33 ± 0.82	0.057	0.688	–	0.068	0.271	–	**0.029**	0.918	0.85
Communication and general problem-solving skills	1.20 ± 0.84	2.67 ± 1.37	0.058	0.691	–	**0.035**	0.873	0.81	**0.032**	0.894	0.75

Mathematical learning achievements: significant values are highlighted in bold. Effect size for non-parametric test: r (small: 0.1; medium: 0.3; large: 0.5) for group differences.

Table 2. Distribution of mathematics learning achievement by areas of cognitive abilities of primary school students with hearing impairment (pretest and posttest results).

						Control group			Experimental group		
Areas of Cognitive Abilities	Control group	Experimental group	*p*-level	Observed power	Effect size	*p*-level	Observed power	Effect size	*p*-level	Observed power	Effect size
Pretest											
Knowledge and understanding	5.80 ± 2.28	7.42 ± 1.32	0.139	0.279	–	–	–	–	–	–	–
Application	5.80 ± 2.28	7.67 ± 4.08	0.359	0.161	–	–	–	–	–	–	–
Higher-thinking skills	0.20 ± 0.45	0.33 ± 0.52	0.637	0.053	–	–	–	–	–	–	–
Posttest											
Knowledge and understanding	8.40 ± 2.07	12.33 ± 1.03	**0.008**	1.000	0.85	0.063	0.489	–	**0.024**	0.851	0.73
Application	6.60 ± 2.97	10.17 ± 3.13	0.052	0.632	–	0.057	0.361	–	**0.035**	0.819	0.76
Higher-thinking skills	6.60 ± 1.67	6.17 ± 1.47	**0.012**	1.000	0.72	**0.011**	0.951	0.82	**0.009**	1.00	0.92

Cognitive ability: significant values are highlighted in bold. Effect size for non-parametric test: r (small: 0.1; medium: 0.3; large: 0.5) for group differences.

Table 3. Levels of mathematics achievements of pupils with hearing impairments (pretest and posttest).

						Control group			Experimental group		
Level	Control group	Experimental group	*p*-level	Observed power	Effect size	*p*-level	Observed power	Effect size	*p*-level	Observed power	Effect size
Pretest											
Satisfactory	6.00 ± 2.40	8.08 ± 1.72	0.119	0.328	–	–	–	–	–	–	–
Basic	6.00 ± 2.58	6.83 ± 3.06	0.309	0.351	–	–	–	–	–	–	–
Advance	0.20 ± 0.45	0.50 ± 0.84	0.560	0.102	–	–	–	–	–	–	–
Posttest											
Satisfactory	4.60 ± 1.67	6.00 ± 0.00	**0.036**	0.951	0.35	0.089	0.624	–	0.061	0.438	–
Basic	11.0 ± 3.39	19.00 ± 3.22	**0.013**	0.995	0.67	**0.009**	1.000	0.91	**0.000**	1.000	0.99
Advance	1.80 ± 1.10	3.67 ± 1.37	**0.029**	0.989	0.26	**0.015**	0.991	0.72	**0.001**	1.000	0.98

Effect size for non-parametric test: r (small: 0.1; medium: 0.3; large: 0.5) for group differences.

advanced results (posttest CG 1.80; EG 3.67; $p = 0.029$). Comparing the EG data before and after gamification established a statistically significant difference in basic ($p = 0.000$) and advanced ($p = 0.001$) levels.

Discussion

The study supports Langdon et al.'s (2023) call for investigating how gamification methods impact on the mathematical achievement of primary school pupils with hearing impairments. Therefore, this paper examines the following research questions: what are the learning needs and difficulties in mathematics of primary school pupils with hearing impairments? What are the mathematics achievements of pupils with hearing impairments? How does the use of gamification in the classroom contribute to the mathematics achievement of pupils with hearing impairment?

Gamification in mathematics lessons for pupils with hearing impairment and its influence on mathematics achievements

Our research was based on the premises, that the application of gamification in mathematics lessons was an important factor in engaging students in lessons, motivating them to actively participate in each lesson, encouraging them to carefully read the conditions of mathematical tasks, developing the abilities of teamwork, discussion and argumentation and the application of various strategies, as found in the studies by López et al. (2021) and Yig and Sezgin (2021). Moreover, for pre-school and first grade pupils with hearing impairment, the use of a tangible game facilitates their understanding of mathematical concepts, resulting in better engagement in teaching and learning (Casimiro et al., 2023). Gamification integrates game elements with the educational dimension. In the experimental stage of the study, games 'with an educational bee' – the robot 'Bee-bot' – were devoted to developing pupils' abilities in the areas of numbers and calculation and statistical activities by predicting and programming the direction of the robot's movement toward the intended goal in advance.

For developing pupils' mathematical communication competencies, including the purpose of explaining and paraphrasing mathematical information presented in various forms (text, picture, scheme, formula, table, drawing, graph, diagram), the interactive team game 'Bamboozle' was used.

The third game method – interactive escape room game with tasks of various types (textual, test, puzzle type, strategic) and linking the written text of the Lithuanian language with the video information provided in the Lithuanian sign language dictionary – was used for pupils' abilities in the areas of numbers and calculation and statistical activities development.

By assessing the distribution of achievement in mathematics by curriculum content, it was found that the predominant level of mathematics achievement in the experimental group was satisfactory level, and the control group was the basic level. Pupils with hearing impairment demonstrated good and satisfactory performance in tasks in numeracy and numeracy content. Before the experiment, both the experimental and control groups performed poorly in tasks requiring higher-level thinking skills. After the experiment using different gamification methods, the achievement level of the experimental group changed from satisfactory to basic and advanced. A significant change in the experimental group was also observed in mathematics tasks requiring higher thinking skills. The results of our study indicated that the educational experiment (gamification) resulted in a statistically significant increase in the distribution of mathematics achievement across the curriculum content: numbers and computation, geometry, measures and measurement.

Gamification applied in mathematics lessons impacts the development of learners' various cognitive abilities. A study conducted by Karamert and Kuyumcu (2021) revealed that the use of gamification in mathematics lessons has a positive effect on students' academic achievements. After a six-week study involving experimental and control groups, higher results were observed in the experimental group, which showed a statistically significant difference ($p = 0.007$). In our study, after eight-week, the second measurement of mathematics progress monitoring showed a positive change in the field of higher reasoning abilities of the experimental group ($p = 0.026$). Pupils showed significant changes in the assessment of cognitive ability groups, and in particular, there was a major change in the assessment of the higher-thinking ability group (pretest – 0.33 points average, posttest – 6.17 points average). Similar results were observed in the research findings of Pontes et al. (2020) and Casimiro et al. (2023). We support the statements of Kim et al. (2018) that gamification effectively develops skills and thinking abilities that are needed to solve more complex mathematical tasks.

Limitations and recommendations for further research

This study has some limitations that are important to note. The sample size is relatively small and quite specific, so the results cannot be generalized to all primary school pupils with hearing impairment. In order to assess more fully the benefits and limitations of using games in mathematics lessons and to see how they are implemented in the classroom, the study design needs to be complemented by a teacher survey, an analysis of pupils' activity digital traces and a larger, more representative random sample from other regions of the country and a variety of primary education schools. In addition, gamification studies have to be related to the discussion of trajectories of mathematical development. There is still a scarce body of research on gamification for primary school hearing-impaired pupils, which allows them to train and acquire learning strategies for mathematics achievement. Universities and schools should offer teacher training courses to facilitate the adaptation of gamification for their pupils with hearing impairment or other special education needs.

Conclusions

After the initial measurement of the test, it was found that the first-grade primary school pupils with hearing impairment in the experimental and control groups had quite similar achievements in mathematics. The pretest mathematics achievement in curriculum content (numbers and calculations, phenomena, equations and inequalities, geometry, measures and measurements, communication and general problem-solving skills) for the control and experimental groups was not statistically different. Both groups' challenging curriculum content areas were geometry, measures and measurements; statistics; communication and general problem-solving skills. When cognitive ability groups (knowledge and understanding, application, higher thinking skills) were assessed in a pretest, it was found that pupils of both groups demonstrated low abilities in solving tasks that required higher reasoning abilities. The dominant level of hearing-impaired pupils' achievement in mathematics for the control group was basic, while for the experimental group it was satisfactory.

The educational experiment of introducing game-based approaches to mathematics lessons for first-grade primary school hearing-impaired pupils resulted in statistically significant improvements in knowledge of numbers, calculations, geometry, measures and measurements. A significant change in the experimental group was observed in mathematics tasks requiring higher thinking skills, knowledge and understanding. The mean scores of the experimental group pupils were significantly higher than those of the control group according to curriculum content. After the gamification, the achievement level of the experimental group changed from satisfactory to basic and advanced. The dominant mathematics achievement level for pupils in the control group remained basic.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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