Impact of NEWTON Technology-enhanced Learning Solutions on Knowledge Acquisition in Pilots Involving Students with Hearing Impairments

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***Abstract*— Contributions: This article presents the results of a study carried out as part of two large-scale pilots and analyzes the impact of the use of modern technologies in education in term of knowledge acquisition in case of students with hearing disabilities.**

Background: Teaching topics from STEM area is a challenging task for all teachers who have students with hearing disabilities in their class. On one hand because of the high degree of difficulty of the information in this field and on the other hand because of the difficulties that students with hearing disabilities face in understanding this information. In this context, the use of modern technologies in education, but especially the way they are used together with traditional ones, can provide great support for teachers of students with special needs.

Intended Outcomes: A set of modern technologies i.e. virtual lab, virtual reality (VR), in the game-based learning context of the EU-funded NEWTON project, were employed in education as part of the Earth Course. The goal was to increase the accessibility of STEM information in the area of natural sciences for the benefit of students, especially those with hearing disabilities.

Application Design: The study targeted secondary school students with hearing disabilities. Content related to natural sciences (i.e. wildlife and sealife) was presented as part of the Earth Course via innovative applications that included virtual laboratories and VR. Avatars were used to support the students with special needs (sign language translation).

Findings: The results of this study demonstrate that the use of modern technologies, combined with game-based learning in science lessons for students with hearing disabilities, contribute to increasing their knowledge level. The best results were obtained when these technologies were used in mixed lessons, alongside the traditional teaching methods.

***Index Terms*—Technology-enhanced learning, STEM, hearing impairments, knowledge acquisition, natural sciences**

I. INTRODUCTION

DEAF and hard-of-hearing (DHH) students struggle with cognitive learning in school, usually being unable to attain the same academic achievements as their hearing peers [1]. Spencer and Marschark observed that any deficits and delays in language acquisition have a profound negative effect on incidental learning, that is basic knowledge accumulated from day-to-day conversations and social interactions [2]. Only 5% of DHH children are born to deaf parents and, therefore, are exposed early on to sign language and the deaf culture. Most DHH children live in a spoken language-centered environment and their exposure to natural „patchwork" of experiential, factual or social related vocabulary is limited. Lederberg, Schick and Spencer noted that language deficits have „cascading effects" [3] in many language-related areas of development. The academic achievement gap between DHH students and their hearing peers widens during the school years, especially in language comprehension of mathematical and scientific content of higher complexity. Marschark and Hauser stated that the performance of DHH students is lower than that of hearing peers in integrating STEM information gained from school into accurate and cohesive representations of scientific facts and explanations because they are less likely to rely on previous conceptual knowledge and structured problem-solving skills [4]. Even when they are provided with adequate teaching support, many DHH students are unable to conceive proper scientific research questions and they lag behind the other non-DHH colleagues [2]. Stinson and Mascio et al. indicate that various alternative computer-assisted teaching strategies for delivering STEM content have been explored, including Augmented Reality (AR), Virtual Reality (VR) and game-based learning activities [5] [6]. However, many of these initiatives were experimental and short-lived and were seldom properly evaluated, as Knoors and Marschark highlighted in [7].

Unlike these, the NEWTON project [8] was a three-and-half-year European Horizon 2020 large-scale research project which not only proposed and developed, but also deployed innovative technology enhanced learning solutions, targeting primary, secondary, and tertiary students across Europe, including DHH students. The NEWTON project technologies included Virtual and Fabrication Labs, AR and VR and multimedia and multiple-sensorial media (mulsemedia). The NEWTON project innovative learning approaches included game-based learning and gamification. NEWTON's goal was to employ these novel

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solutions to improve the learning process, increase learning outcome, and most importantly enhance learner quality of experience (QoE), specifically for STEM education.

The purpose of the study described in this paper is to evaluate the impact of the use of some of the NEWTON modern educational technologies in two NEWTON project pilots, both as the primary method of teaching and as revision. The pilots involved the NEWTON Earth Course, a large-scale technology-enhanced learning deployment which employed Virtual Lab and VR technologies in a game-based learning context. Earth Course is a digital course which aims to increase the accessibility of information in the area of natural sciences. The course includes two educational game applications (called *Wildlife* and *Sealife)* in multiple learning sessions. Avatars were also used for sign language translation to support the students with special needs. The pilots were run in two different special educational institutions and involved students with different degrees of hearing impairments. There are two major research avenues in this study: i) evaluation of the impact of the use of NEWTON modern technologies and game-based learning on knowledge acquisition by students with hearing impairments and ii) analysis of the impact of using NEWTON technologies and game-based learning as a primary method of teaching and revision compared to using these technologies in combination with traditional teaching methods (mixed lessons) for DHH students. In summary, this study focuses on assessing knowledge acquisition by DHH students when employing modern technologies and targeting a STEM curriculum.

This paper is structured as follows. Section II discusses some related works highly relevant for the study described in this article. Section III provides details about the NEWTON project and its innovative contributions and describes the STEM-based Earth Course. Section IV presents the two pilots which involved two different cohorts of DHH students, whereas section V includes the results and result analysis. Conclusions are drawn and future research directions are discussed in section VI.

II. Related Works

Johnson et al. stated in [9] that technology-enhanced learning not only encompasses, but also benefits from the cutting-edge technologies such as AR and VR and uses learning analytics as tools for creating an enriched multimodal learning environment. Franklin [10] and Horner [11] noted that following two years of pandemic restrictions, technology-assisted education came back to the center of public attention. Both authors highlighted technology-enhanced learning's obvious advantages in terms of support for accessibility, mobility and versatility and underscored its limitations related to being relatively superficial, potentially distracting, and occasionally vulnerable to academic dishonesty. However, Dunleavy, Dede and Mitchell noted the latest cultural and technological shift [12] which puts pressure on teachers, media specialists, and school administrators to update and upgrade continuously not only the material, but also the manner the content is presented to students in order to remain relevant in the current digital education age.

Game-based learning has emerged from the larger field of "serious games" [13], as a novel approach to teaching, drawing on game mechanics, aesthetics, narratives, and incentives to make learning more appealing and, as Schrader has noted in [14], also more effective.

Serious games are games designed specifically for purposes other than or in addition to pure entertainment [38]. Examples of serious games include games for health staff training and practical skills development, games for advertising, political games, security and disaster control games etc. Educational games are a subset of serious games and imply games explicitly designed for educational purposes to be employed in formal educational settings. They are used to teach students or reinforce certain academic concepts. Game-based learning approaches involve the use of educational games in classrooms.

According to Whitton [15], games are commonly characterized by competition, challenge, exploration, fantasy, goals, interaction, outcomes, people (players), rules, and safety. The over-arching trait of games is "fun", but this is the subjective assessment of the player(s). An important part of the game experience is the progress from learning the game to winning the game. The main challenge of game-based learning is to find ways to mimic the game process for educational purposes, maintaining the "fun" element during learning in general and during the consumption of actual STEM content, which is not always considered attractive.

Digital game-based learning relies on digital games to deliver academic knowledge and shape skills and attitudes towards scientific research and reasoning by making use of the aforementioned game characteristics. There is a delicate balance between task requirements and playfulness. As Abt said, "games may be significant without being solemn, interesting without being hilarious, earnest and purposeful without being humorless, and difficult without being frustrating" [13].

Mayer [16] proposed four different perspectives about the use of computer games for learning. The *motivational perspective* has traditionally been mentioned as the most significant advantage acknowledging the "addictive" trait of best computer games. Closely related to this is the *affective perspective*, enhanced by the "emotional design" of the game noted by Plass and Kaplan [17], which is usually reported as a positive emotional experience. The *sociocultural perspective* takes into consideration all interactions of the player, human or fictional, leading to in-game collaboration and cooperation. Finally, there is a *cognitive perspective* when aroused intrinsic motivation and positive emotional experience foster further investment in cognitive learning.

The vital link between intrinsic motivation and positive emotions is promptly reinforced by instant feedback, an essential component of successful computer games, usually provided through audio, video, and haptic sensory means. However, Schrader noted that excessive feedback input, too much guidance or support, heavy cognitive load, repetitive tasks etc. may disrupt the "game flow" [14], making the experience less engaging.

While game-based learning uses games to make the learning process fun and immersive, Swink stated that gamification transfers game-based elements to other types of activities aiming to add a "game feel" [18] flavor to them. Learning the content, and not winning the game, is the purpose of using gamification in education.

Gamification involves the use of game design elements in non-game context to encourage participation. Besides the reward system and leaderboards, gamification focuses on content learning, problem solving, skill training, or attitude changing. Gamification delivers the same task in an engaging game mock-up. Game-based learning redesigns the task according to game mechanics, aesthetics, storytelling, reward system, goal achievement maintaining the same learning objective as traditional teaching [19]. Playful learning may use game features to redesign a learning task, without affecting its core elements as stated by Plass et al. [20]. They advocated tweaking and modding to add new avenues to the same game, creating a sense of owning the game, therefore enhancing motivation and emotional attachment of the user.

Kapp noted that simulations are not actual games, but plausible, life-inspired environments designed to offer realistic learning and training contexts, bridging theory and practice [21]. De Freitas and Maharg observed that the games are more rule-based and structured while simulations allow flexible and exploratory approaches [22]. Games usually force the user to follow one or a handful of prescribed game scenarios, whereas simulations expect the user to create and try to experiment with novel approaches in a predetermined virtual setting.

Milgram et al. focused on interactive technologies, which are able to provide different levels of immersive experiences along a continuum of mixed reality settings [23]. While AR overlays digital content on real-life environment, VR creates a fully imaginary environment requiring an avatar to navigate and complete tasks in a computerized setting [24].

Using technology-enhanced learning methods involving children with disabilities has been challenging and limited. Recently, Ellis, Leaver, and Kent noted that there is a noticeable interest in the field of game studies concerning accessibility and diversity [25]. Students with disabilities usually have many special educational needs added to those caused by their primary disability. For example, Ewing and Jones reported that up to 50% of the DHH students may also have additional disabilities such as ASD, visual, intellectual, and learning disabilities [26]. Attention span, information processing, memory storing and retrieval, literacy and pragmatics deficits may also hinder the learning performance of DHH students. Beavis noted that there is a wide range of diversity among regular students and teachers alike regarding games and gameplay [27]. Jones, Jones and Ewing stated that heterogeneity of multiple disabilities [28] adds up to the variety of individual set of special educational needs. Therefore, the benefits of using technology-enhanced learning involving children with disabilities are up to be researched, especially in a context where authors such as Dunleavy, Dede and Mitchell, Radu and Rodrigues et al. agree that the most frequent disadvantages (e.g. distraction, attention tunneling, poor task understanding, excessive cognitive load, ineffective classroom integration, usability difficulties, higher fatigue rate) [12], [29], [30] are still difficult to overcome without dedicated AR/VR content, digital game-based learning or gamified educational applications. In a context in which untrained regular students may already experience certain difficulties using novel technology-enhanced contents and devices, DHH students face increased challenges and require custom-tailored educational contents and applications. This tailored support focuses on using combined verbal and visual information instead of sequential input, emphasizing background knowledge and downsizing content knowledge, in order to avoid cognitive and working memory overload. Knoors and Marschark stressed the importance of teacher mediated multimedia instruction based on carefully selected content, spatially closed presentation of verbal and visual materials, and retention of essential visual information [7].

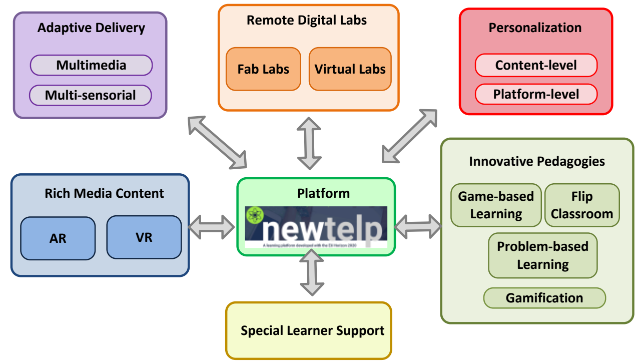

Fig. 1 The major contributions of the EU NEWTON project

The research presented in this paper makes a step forward beyond the state of the art, as it uses the latest innovative technologies such as AR/VR and Virtual Labs in two game-based learning applications developed and deployed by the EU Horizon 2020 project NEWTON to deliver interactively STEM content to DHH students in complex educational settings.

III. The NEWTON Project and the Earth Course

A. Overall Project Description

The NEWTON project was a 14-partner large EU Horizon 2020 project which proposed innovative technological solutions for distribution of STEM content to diverse learners. The project designed solutions for adaptive and personalised rich media content delivery, including multimedia, mulsemedia, AR and VR, online Virtual teaching and learning Labs (Virtual Labs) and remote Fabrication Labs (Fab Labs), which are referred to as NEWTON innovative technologies. These NEWTON technologies were designed to be employed in diverse educational contexts along with various innovative pedagogical methods, including game-based, problem-based and gamification-based approaches. A new learning management platform NEWTELP was also designed and built to deploy the NEWTON solutions. NEWTELP enabled learners and teachers from multiple EU countries to avail of NEWTON solutions and access innovative educational content. Figure 1 illustrates NEWTON's project major contributions.

Fig. 2 The Wildlife Serious Game a) Free search for wild animals b) Localisation of a Deer and learning about it c) Detailed study of the Deer in a virtual lab

Fig. 3 The Sealife Serious Game a) Free search for sea animals b) Localisation of a Clown Fish and learning about it c) Detailed study of the Clown Fish in a virtual lab

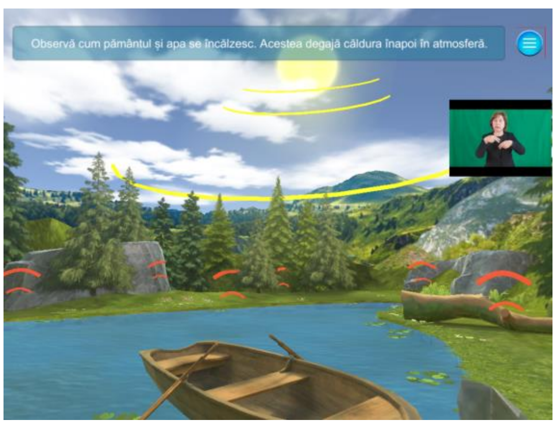

Fig. 4 Illustration of an avatar for sign-language translation and subtitles in a local language

During the NEWTON project, multiple educational AR and VR applications, educational games and Virtual and Fab Labs were designed and developed. Avatars and subtitles were employed for sign language and classic language translation in local languages, as illustrated in Figure 4. These project outputs were tested in real life deployments in 20 educational institutions from six European countries. They delivered content on STEM topics to primary, secondary and tertiary level students, including to some students with special educational needs. For example, Fab Labs were employed to improve the learning experience of secondary school students from Ireland and Spain [31], VR applications and Virtual Labs were used to deliver STEM content to Irish primary school students [32], and educational games deploying various game-based learning methods were at the center of a novel programming course taught to university students in Ireland and Slovakia [33]. The NEWTELP platform hosted the educational content and applications, enabled student access to NEWTON technologies and supported student evaluation [34]. The evaluation focused on various aspects, including learner quality of experience, knowledge acquisition and platform usability and was performed according to a novel methodology outputted by the NEWTON project [35].

One of the most important outputs of the NEWTON project was the deployment of a series of educational games for student education. In an educational context, educational games are games designed specifically for student teaching and learning. They integrate the educational content with various game elements to attract students' interests. They also employ game features to make them entertain the players and use interactivity to actively engage with the students. In this context, the educational games' goal is to increase student learning motivation and make their learning experience fun. This is as employing games in the educational process is proven to be a great motivator for learning [8], [36]. The games should not only make students learn useful content regardless of how much they are originally attracted to it, but also determine them to learn it better.

B. The Sealife and Wildlife Game Applications

The *Wildlife* application is an educational game which uses VR and 3D immersive Virtual Lab technologies to present forest life and is part of the larger NEWTON project's *Earth Course*. Students can either use a VR headset or run the application on a tablet or a PC. Special sounds, haptic feedback and an avatar for learners with special educational needs allow the users to perceive and interact with the VR content or engage with the Virtual Lab. Interactive activities are embedded within *Wildlife*.

The *Wildlife* application includes two separate environments. The first environment illustrated in Figure 2 a) and Figure 2 b) is a nature-like VR environment, where the participating learners embark on a journey at the wheel of an off-road vehicle and drive around a forest in a quest to discover animals. The second environment shown in Figure 2 c) is a Virtual Lab environment, in which the students benefit from a closer view of the animals along with access to additional educational information related to them. Multiple animals are focused on, including deer, wolf, wild boar, fox, moose, brown bear, hare and lynx. In particular, Figure 2 illustrates the *Wildlife* game and the two types of environments that enable following a search for an animal in an interactive manner (a), finding the animal, a deer in this case, and learning some data about it (b) and having access to detailed information about the deer in a Virtual Lab context (c).

In their game journey, the students are asked to find animals in their VR habitat and learn science facts about them, whereas in the 3D immersive Virtual Lab they can look at the animals in more detail and discover fun facts about them. Finally, the students are asked to answer multiple choice quizzes and get points. Apart from being highly educative and attractive, *Wildlife* also has the additional benefit of being suitable for students with special educational needs, specifically hearing impairments.

The *Sealife* educational game application focuses on the aquatic world and, similar to the *Wildlife* application, is also part of the NEWTON project *Earth Course*. It presents educational content through a game play experience regarding various water animals, where students embark on a journey at the wheel of a boat and then dive into the sea to find sea animals and discover important information about them. Students can access the *Sealife* application either by using a VR headset or via a tablet or a PC. Special sounds, haptic feedback and an avatar for sign language allow a wide range of learners to access and interact with the VR environment.

Diverse interactive activities are embedded within *Sealife* in two stages. In the first stage, players are asked to find animals in the sea and learn science facts about them, while engaged in a nature-like VR environment. In the second stage, within a Virtual Lab the participants can observe the animals in more detail and learning fun facts about them. At the end, the users are invited to answer multiple choice quizzes which enable them to accumulate points. The sea animals introduced by the application include dolphin, jellyfish, octopus, orca, turtle, clownfish, puffer fish, seahorse, shark and stingray. Figure 3 illustrates the *Sealife* educational game application with the two types of environments that enable the search for an aquatic animal using a boat and then diving into the sea Figure 3 a), finding a clown fish and learning some data about it Figure 3 b) and having access to detailed information about the clown fish in a Virtual Lab context Figure 3 c).

Notably, like *Wildlife*, the *Sealife* application is suitable for students with special educational needs, specifically those with hearing impairments, as it employs an avatar for sign language.

Both *Wildlife* and *Sealife* applications were developed by the NEWTON project consortium partner SIVECO, Romania following interaction with other project researchers and teachers from multiple institutions, including some teachers with experience in the education of students with special needs.

IV. Methodology

The case study presented in this paper consisted of two pilots that were run in two different educational centers whose main activity is teaching students with hearing disabilities. The two pilots used both the *Wildlife* and *Sealife* applications, part of the larger NEWTON project *Earth Course*.

Pilot A was deployed in the Special Vocational School for Students with Hearing Disabilities “Sfanta Maria”, Bucharest, Romania and used the NEWTON solutions as the main method of teaching STEM knowledge in the natural sciences area. Pilot B was deployed at the Special Technological High School for students with hearing disabilities Buzau, Romania. As part of pilot B, the NEWTON solutions were used as a revision method in mixed lessons, alongside traditional methods, which were used as the main way of teaching.

Participants

The study included 62 students with hearing disabilities aged between 9 and 19 years, who attend the classes of a special school for students with hearing disabilities. The selection criteria of the sample were: presence of a hearing disability, enrollment in a special school for students with hearing disabilities, inclusion of subjects on science (i.e. terrestrial animals and marine life) in the curriculum. The participants were grouped into two pilots, as follows:

Pilot A involved 30 DHH students between 9 and 18 years old, with different levels of disability, from mild to profound impairments. In terms of gender, 19 male students and 11 female students were included in this pilot. Regarding students’ background, 9 of them live in big cities, 10 in small cities and 11 live in the countryside.

Pilot B included 32 students with different degrees of hearing disabilities, from mild to profound impairments. The participants were aged 11 to 19 years and 17 of them were male and 15 were female students. 12 of the students came from big cities, 2 from small cities and 18 lived in the countryside.

The students' participation in the study was voluntary and was based on the informed consent given by the parents. The students also signed a participation agreement. If a student did not give their consent for participation, they were not included in the study, even if their parents signed the consent form. The students were informed in detail about the study using plain language with the help of the specialized staff. Each student had the right to withdraw from the study at any time. To ensure the anonymity of the data, each student was assigned an individual code, and their name was not used. In order to ensure the DHH students' comfort, the lessons were taught by their own teachers after being previously trained by the NEWTON project team for correct use of technologies. This procedure received approval from the relevant Ethics committees at local level and that of the European project coordinator’s institution.

Pilot A - Earth Course "Sfanta Maria"

In this Pilot, the NEWTON technologies included in the Earth Course were used both as a primary method of teaching knowledge and as a revision method and took place at the Special Vocational School for the students with hearing disabilities "Sfanta Maria”, Bucharest, Romania.

The selection of lessons and their educational content has been decided together with the teachers from the school. This was to ensure that the information presented is in line with the curriculum and it is accessible to the students with hearing disabilities. These lessons included *Sealife* and *Wildlife* game

TABLE I
EVALUATION PROCESS

Stage	Task
Before the pilot	Demographic questionnaire
	Knowledge pre-test
During the pilot	Knowledge mid-term test after teaching phase
	Teachers and NEWTON representative researcher observation
After the pilot	Knowledge post-test

applications, which were accessed using PCs. Because of the high information content that these two applications contain, they have been divided into two lessons each: *Sealife 1*, *Sealife 2*, *Wildlife 1* and *Wildlife 2*.

All lessons were provided through the NEWTELP platform, and the activities were conducted by the teachers in the presence of a researcher, representative of the NEWTON project team. The activities were carried out with small groups of students (up to 10 students at a time) in order to ensure that each student had sufficient time to go through the lessons at their own pace.

The pilot ran over one month with 3 lessons per week.

Pilot B - Earth Course "Buzau"

In the second pilot, NEWTON technologies were introduced in mixed lessons alongside traditional teaching methods. In these mixed lessons, traditional methods were used as the main methods of teaching knowledge and NEWTON technologies were used as a revision method. This pilot was carried out in the Special Technological High School for students with hearing disabilities in Buzau, Romania.

The educational content of the lessons and their structure were identical to those used in the Earth Course "Sfanta Maria". The lessons were also conducted in small groups of students who used PCs. There were 3 lessons per week over a one-month period.

Reproducibility

The study was carried out with the participation of students with hearing disabilities who are educated in special schools and benefit from teachers specialized in working with students with such deficiencies (e.g. they know and use the sign language). This study can be reproduced on any groups of students with hearing impairments, which benefit from specialized support.

Pilots Evaluation Process

The case study evaluation followed the four-stage process illustrated in Table I. It consisted of knowledge tests that were applied initially before the pilot started, intermediately after the completion of the knowledge teaching and finally after the revision session. The questions of the knowledge tests were designed together with the teachers from the educational institutions which hosted the two pilot groups and were the same for both pilots.

Table II shows a sample of questions from the knowledge test and the choice of answers available to the students.

Table III presents the development chart of all educational activities in order to both present the overall teaching and assessment process as well as clarify the major differences between the two pilots.

TABLE II
KNOWLEDGE TESTS – SAMPLE ITEMS

Knowledge test	Questions and answers
Wildlife pre-test	What do herbivorous animals feed on? (One correct answer only) a) Insects. b) Animals. c) Plants. d) Fish e) I don't know.
Wildlife post-test	Wolves live in …. (One correct answer only): a) Seaside areas. b) Forests. c) Big cities. d) On the rocks. e) I don't know.
Sealife pre-test	Jellyfish are … (One correct answer only): a) Carnivores. b) Herbivores. c) Omnivores. d) I don't know.
Sealife post-test	Why do turtles dive to great depths? (There is only one correct answer) a) To hide from the light. b) To hide from predators. c) To find zooplankton. d) To lay eggs. e) I don't know.

V. RESULTS AND ANALYSIS

For statistical analysis of the data in our study, the following methods were used:

- t-test for independent samples to analyze the mean differences between the results collected following the initial testing in the two groups of the study (in order to make sure that the students in the two groups start from the same level of knowledge)
- t-test for paired samples to capture the differences between initial testing - mid-term testing and initial testing - final testing, respectively
- t-test for independent samples for the analysis of the average differences between the results obtained in the final test between the two groups of students (in order to assess any differences in the progress between the two groups)
- Cohen's test for effect size measurement.

A. Initial test results

Testing the difference between the means of the initial knowledge level (prior to the educational intervention) obtained in the two groups of students with hearing impairments using t-tests with independent samples showed no statistically significant differences between the two groups of students (Pilot A and Pilot B) for both *Sealife* and *Wildlife* applications. *Sealife 1* (mA=1.73, mB= 1.67, t=0.24, df= 60, p= 0.40); *Sealife 2* (mA= 2.33, mB= 2.37, t= -0.13, df= 60, p= 0.44); *Wildlife 1* (mA= 1.83, mB= 1.68, t=0.57, df= 60, p= 0.28) and *Wildlife 2* (mA= 1.7, mB= 1.53, t=0.6, df= 60, p= 0.27). Therefore, in terms of knowledge already acquired at the time of inclusion in the study, there are no significant differences between the students with hearing disabilities in the two research groups.

TABLE III
DEVELOPMENT CHART OF ACTIVITIES

Pilot	Pre-test knowledge	Traditional method teaching	NEWTON teaching	Intermediate knowledge test	NEWTON knowledge consolidation	Knowledge post-test
A	✓		✓	✓	✓	✓
B	✓	✓		✓	✓	✓

A. *Intermediate test results*

At the end of the first stage of the intervention, after the teaching of learning content (using NEWTON technologies in pilot A and traditional methods in pilot B), in both groups and for both lessons, a significant progress was observed comparing to initial tests. Differences observed based on descriptive analysis were also analyzed using the paired sample t-test. Its results revealed statistically significant differences between the initial evaluation results and the evaluation results at the end of the first intervention phase for both learning contents - *Sealife* and *Wildlife* - for both research groups (Table IV).

Although the progress made by the students of the two pilots is significant, a comparative analysis of the mid-term test results between the two pilots showed that in the *Wildlife* - 1 and 2 lessons, the progress was greater in Pilot A. Thus, the academic results obtained by the group of students at "Sfanta Maria" School in Bucharest for both evaluation sessions (*Wildlife 1*, *Wildlife 2*) following teaching based on the use of NEWTON technologies as the main teaching method are significantly higher than the group of students at the Technological High School in Buzau (where traditional methods were used) for both *Wildlife 1* (m1=3.76, m2= 3.15, t (60)=2.16, p= 0.017) and for *Wildlife 2* (m1= 3.93, m2= 3.25, t (60)=2.10, p= 0.020).

B. *Final test results*

After completing the consolidation phase of the content taught using NEWTON technologies in both study groups, academic results improved significantly (see Figure 5 and Figure 6). Statistically significant differences between the pretest and post-test results for both learning contents (*Sealife 1*, *Sealife 2*, *Wildlife 1* and *Wildlife 2*) were revealed by the paired samples t-test for both groups participating in the study as shown in the data included in Table V.

Between the two groups of students with hearing disabilities there are statistically significant differences in post-test scores for all learning content. For instance, for *Sealife 1*, the results m1=3.98, m2=5.7, t (60)= -6.16, p <0.001, Cohen's d = 1.098 show how following the use of innovative NEWTON technologies, students from Pilot B performed significantly better than the students from Pilot A. Similar results were obtained also for the *Sealife 2* course, with the following statistical analysis results: m1= 5.43, m2=6.48, t (60)= -2.62, p <0.050, Cohen's d = 1.577 for *Wildlife 1* and *Wildlife 2*, which had m1= 4.46, m2=5.75, t (60)= -4.71, p <0.001, Cohen's d = 1.072 and m1=4.46, m2=5.28, t (60)= -2.82, p <0.010, Cohen's d = 1.136, statistical data analysis results, respectively.

TABLE IV
STATISTICALLY SIGNIFICANT DIFFERENCES BETWEEN THE PRE-TEST KNOWLEDGE EVALUATION - MID-TERM TEST

Pilot A		**Mean**	**Std. Dev.**	**t**	**p**	**Cohen's d**
Pair 1	Sealife 1 pre-test - Sealife 1 mid-term evaluation	-1.850	1.340	-7.562	0.000	1.340
Pair 2	Sealife 2 pre-test - Sealife 2 mid-term evaluation	-2.467	1.833	-7.370	0.000	1.833
Pair 3	Wildlife 1 pre-test - Wildlife 1 mid-term evaluation	-1.933	1.172	-9.032	0.000	1.172
Pair 4	Wildlife 2 pre-test - Wildlife 2 mid-term evaluation	-2.233	1.675	-7.303	0.000	1.675
All	df = 29					

Pilot B		**Mean**	**Std. Dev.**	**t**	**p**	**Cohen's d**
Pair 1	Sealife 1 pre-test - Sealife 1 mid-term evaluation	-1.883	1,260	-8.450	0.000	1.260
Pair 2	Sealife 2 pre-test - Sealife 2 mid-term evaluation	-2.414	1,346	-10.142	0.000	1.346
Pair 3	Wildlife 1 pre-test - Wildlife 1 mid-term evaluation	-1.469	0.718	-11.576	0.000	0.717
Pair 4	Wildlife 2 pre-test - Wildlife 2 mid-term evaluation	-1.719	0.888	-10.944	0.000	0.888
All	df = 31					

C. *Discussion*

This study aimed to assess the impact of using NEWTON technologies on the acquisition of knowledge in the STEM area of science for students with hearing disabilities. The initial testing, conducted prior to the implementation of the two pilots under review showed a low level of student knowledge in both Pilots for both courses (*Sealife* and *Wildlife*). The differences in means on the initial test between the two pilots were not statistically significant, which shows that both groups started from the same initial level of knowledge.

The first stage of intervention involved teaching the topics, differently as follows: in Pilot A, knowledge was taught using exclusively NEWTON approaches, while in Pilot B knowledge was taught using traditional methods. In both pilots the content of the lessons was identical, but the form of delivery was different. At the end of this stage, a mid-term evaluation was conducted based on knowledge tests, identical for both pilots, which enable fair comparison. The mid-term test evaluation showed that both groups of students scored significantly higher than in the initial test, demonstrating the success of the teaching and learning process.

TABLE V
COMPARATIVE ANALYSIS OF INITIAL TEST RESULTS VS. FINAL TEST RESULTS PILOT A AND PILOT B

Pilot A		**Mean**	**Std. Dev.**	**t**	**p**	**Cohen's d**
Pair 1	Sealife 1 pre-test - Sealife 1 post-test final	-2.250	1.097	-11.238	0.000	1.096
Pair 2	Sealife 2 pre-test - Sealife 2 post-test final	-3.100	1.470	-11.547	0.000	1.470
Pair 3	Wildlife 1 pre-test - Wildlife 1 post-test final	-2.633	1.090	-13.239	0.000	1.090
Pair 4	Wildlife 2 pre-test - Wildlife 2 post-test final	-2.767	1.472	-10.292	0.000	1.472
All						df = 29
Pilot B		**Mean**	**Std. Dev.**	**t**	**p**	**Cohen's d**
Pair 1	Sea Life 1 pre-test - Sealife 1 post-test final	-4.023	1.190	-19.122	0.000	1.190
Pair 2	Sealife 2 pre-test - Sealife 2 post-test final	-4.109	1.388	-16.745	0.000	1.388
Pair 3	Wildlife 1 pre-test - Wildlife 1 post-test final	-4.063	1.216	-18.891	0.000	1.216
Pair 4	Wildlife 2 pre-test - Wildlife 2 post-test final	-3.750	1.016	-20.879	0.000	1.016
All						df = 31

Figure 5 illustrates the student results in the pre-, mid-term and post-knowledge tests in Pilot A and Pilot B, respectively. Comparative analysis of the results of the two groups of students showed that the progress made by the students in Pilot A was significantly higher than that achieved by those in Pilot B in the two *Wildlife* lessons. This analysis shows that the use of modern technologies as the main method of teaching knowledge about terrestrial animal life is more effective than the use of traditional methods. It has been observed that this statement is not validated for knowledge about marine animal life. Based on observations made by the researcher representative of the NEWTON project during the lessons, it was found that information about terrestrial life was more accessible to students with hearing disabilities than information about marine life and did not raise as many questions from students. The situation was different, however, for lessons on marine life, where information was less accessible to students and required additional explanations from teachers that the technology-only lessons could not provide.

In the second phase of the implementation of the two pilots, the consolidation of the knowledge taught in the first phase was achieved by using NEWTON technologies in both pilots. Figure 6 compares Pilot A and Pilot B post-test results. Analysis of the mean scores received by students on the final tests showed a significant improvement in knowledge of terrestrial and marine life for both study groups. However, the analysis of mean differences of final results between the two groups of students showed significantly better progress in the group of students included in

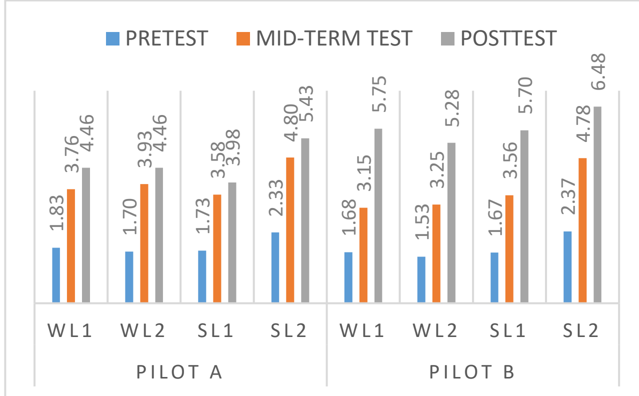

Fig. 5. Comparison between pre-, mid-term and post-knowledge tests (pilot A and Pilot B).

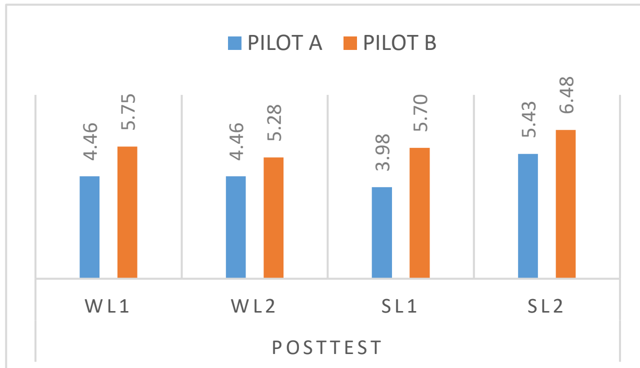

Fig. 6. Comparison between Pilot A and B - post-test results

Pilot B, where the teaching of knowledge was achieved by traditional means and NEWTON technologies as well. This demonstrated that when teaching students with hearing disabilities, it is more effective to use modern learning technologies alongside traditional teaching methods, improving the effectiveness of the overall learning process. By using traditional methods, the context is set in such a way that students can ask for and receive additional information and explanations from the teacher where these are needed. These explanations are especially important in the context of students with hearing disabilities as they have different ways of processing information than typically developed children, and some information is not as accessible to them.

There is a scarcity of studies and projects investigating technology-enhanced learning and STEM education for DHH students. Knoors and Marschark noted that the relevant literature was limited to brief descriptions of programs, usually lacking evaluation of multiple media use and outcomes [7]. They discussed a handful of projects such as SMILE (3D game intended to be used in K through 12 math and science education), Project Solve (focused on problem-solving instruction and guided practice), LODE and TERENCE (fostering global reasoning and comprehending reasoning on e-stories). ASL STEM CLeaR was a project designed to facilitate access of DHH students studying STEM content [37]. STEMSiL is a consortium project aiming to review existing STEM-related signs/concepts in five European Sign Languages and, subsequently, to compile a bilingual handbook regarding STEM methodologies in sign languages [39].

The empirical review and analysis performed by Schrader [14] indicate that game-based learning and serious games have a strong impact on learner motivation, affect and cognitive learning outcomes. Game-based learning approaches foster motivation, positive emotions, and deeper learning. Although Schrader's study focused on research work that involved educational games provided to learners with no disability, the outcomes of the research presented in this paper confirms the positive impact game-based learning has on cognitive learning on DHH students, too.

Bogusevschi et al. [32] investigated the effectiveness of VR and Virtual Lab technologies as part of a small-scale educational pilot that has used a Water Cycle in Nature application deployed in a secondary school with students with no disabilities. As the application did not include a game-based learning approach, the research findings have shown only the positive impact of the use of NEWTON modern technologies on students' knowledge gain when VR and Virtual Lab are used as a primary method of teaching. The work reported in this paper confirms the results of that preliminary study and extends the previous work by combining NEWTON modern technologies with game-based learning and avatars seeking to improve the knowledge acquisition specifically for students with hearing impairments.

To the extent of authors' knowledge, the NEWTON study described in this paper is the first transnational systematic attempt to design, implement, assess, revise, and disseminate STEM-based natural sciences learning content through multiple modern technologies to DHH students and its results are highly promising. These technologies are extremely valuable for teachers and students alike as they help increase the access to information of DHH students and contribute positively to their educational development.

D. Limitations of the Study and Recommendations

An important limitation of this study is that the pilots were carried out with DHH students who are educated in special schools and in the presence of teaching staff specialized in the activity with students with hearing disabilities (e.g. teachers who know the sign language and were able to answer students' questions, in a way accessible to them). There are some concerns regarding generalization of the results of this study when students with hearing impairments included in general schools and who do not benefit constantly from specialized support are considered.

A very important observation in this study was that the success of technology-enhanced lessons is dependent on the skills the students have in using modern technologies. Thus, for similar studies it is recommended for students with limited skills in the use of technologies, to plan additional meetings in advance, so that they can familiarize themselves with any novel devices and technologies included in lessons.

VI. Conclusions

This article presented a study that introduced the use of modern technologies (e.g., Virtual Lab and VR) in combination with game-based learning in the education of students with hearing impairments, more specifically in teaching of knowledge in the STEM area related to natural sciences. The specific cognitive processing of information in students with hearing disabilities makes it difficult to understand abstract information and especially information that is not part of their everyday life. Under these conditions, the information content specific to the STEM curriculum area is generally difficult to understand by these students, which is why, in this study, we started from the premise that the use of modern technologies can contribute to increasing the level of understanding and, implicitly, to that of knowledge acquisition. Modern technologies can be used in schools both on their own and alongside traditional teaching methods. Under these circumstances, we conducted a comparative analysis of the impact that NEWTON technologies enhanced with game-based learning have on the learning process when included in technology-only and mixed lessons.

The results of the mid-term evaluation, after the teaching stage, allow us to state that the use of modern technologies in a game-based learning context as the main way of teaching STEM knowledge to students with hearing disabilities is more effective than traditional methods, as the information taught is accessible and does not involve much additional explanation. Where information is more difficult to understand, the effectiveness of modern technologies is similar to that of traditional teaching methods.

The final evaluation, carried out after the revision phase, showed that the most effective way of using modern technologies in combination with game-based learning in teaching STEM information to students with hearing disabilities is in mixed lessons as a way of revision method of knowledge taught by traditional methods. Both groups of students made significant progress in knowledge acquisition since the pretest, but progress was significantly greater in the group of students, where mixed lessons were used.

Modern technologies deployed as part of an educational game used in teaching and learning for students with hearing disabilities are an extremely valuable support for teachers and can contribute to increasing access to information for these students, especially if they are used in accordance with the specific development of these students.

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