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Learning sign language with mixed reality applications - the exploratory case study with deaf students

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Abstract
The current body of scholarly literature highlights the increasing importance of Mixed Reality (MR) in the field of education since it provides an alternative way through visual stimuli inside an immersive environment. In recent years, the possibility for educators to use Mixed Reality as an additional pedagogical instrument has witnessed notable growth. Furthermore, the implementation of MR technology enhances the perceived benefits of employing it as a solution to the challenges encountered in educating and acquiring sign language skills among children who have hearing impairments or are deaf. The development and testing of deaf-friendly techniques for teaching sign language to Deaf or Hard-of-Hearing (DHH) pupils utilizing modern MR technology is the key endeavor of our research. In light of the specific aspects of the pilot study and the suggestions and preferences expressed by the participants, as outlined in previous attempts, we have endeavored to develop a series of instructional modules on the topic of animals. These modules employ various methods of sign demonstration and incorporate visual representations and concise encyclopedic descriptions. To achieve our research objectives, a total of 21 deaf students, ranging in age from 9 to 14 years, were selected for this study. These students study in a mainstream school that have inclusive educational programs. The participants have been offered two options for evaluation: a laptop and the application specifically designed for the HoloLens 2.

Keywords Mixed reality · sign language · human-computer interaction · human-robot interaction

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1 Introduction

Mixed reality (MR) is a field of computer research that focuses on merging real-world and computer-generated content. In MR, computer-generated virtual graphical objects are seamlessly integrated into the physical space in real time, providing an interactive experience represented in three dimensions.

Mixed reality systems may be recognized as the epitome of immersive technologies. MR systems are usually built as optical see-through systems, often utilizing transparent displays or lenses. MR systems involve marker systems, where markers are added to the physical world scene. Digital 3D objects are not merely superimposed but firmly attached to the physical realm, allowing for interactive engagement. Mixed reality headsets such as Microsoft HoloLens[1] or Magic Leap[2] are usually employed. Meta Quest 3[3], also includes the option for Mixed Reality (MR) since June 2023.

The integration that blends virtual and real-world settings may help to enable a more immersive and engaging learning experience. In recent years, MR technology has acquired popularity alongside traditional teaching approaches in education by giving students with dynamic visuals and simulations that allow them to experiment and explore within the MR context (Liu et al., 2022). MR has also been successfully implemented in science education (Arici et al., 2019), learning languages (Vazquez et al., 2017), and human-robot interaction (Hennerley et al., 2017; Radu et al., 2021).

Evidence from previous research shows that studying in the MR environment can dramatically boost students' motivation and cognitive gains (Diegmann et al., 2015). Furthermore, MR gives teachers new methods to engage students by giving them the opportunity to interact, problem-solve, self-direct, and create in mixed reality (Mateu et al., 2014; Donally, 2022).

It has been especially appreciated in the area of inclusive education because it provides the capacity to enhance inclusivity to learners with impairments, overcome their obstacles, and allow them to become involved heretofore unimaginable interactive learning opportunities (Bacca Acosta et al., 2014). Our research aims to overcome these issues by utilizing an MR application in the context of sign language teaching and learning.

Although some scientific evidence already exists, using MR to enhance teaching and learning sign language has not yet been thoroughly investigated. One of the most notable benefits of MR technology is the ability for DHH persons to practice (watch, repeat, and memorize) signing along with holographic virtual agents in real-time mode (Adamo-Villani & Anasingaraju, 2017; Miller et al., 2017; Shao et al., 2020; Yang et al., 2022).

A student who is DHH(deaf or hard-of-hearing) experiences a hearing impairment, with or without the use of hearing aids, that affects their ability to absorb language information and hinders their performance in an educational setting. The extent of loss might vary from slight to severe.

[1] https://www.microsoft.com/en-us/hololens

[2] https://www.magicleap.com/magic-leap

[3] https://www.meta.com/quest/quest-3/

Extensive studies have compared the efficacy of Visual or Interactive Multimedia Learning with Traditional learning in several fields (Kim et al., 2008; Biffi & Woodbury, 2018), as well as AR (augmented reality) vs. Traditional Learning (Shiue et al., 2019). These studies have unanimously shown the advantages the formers have revealed over traditional learning approaches.

Deaf and hard-of-hearing (DHH) students are unable to process information through a blend of visual and auditory modalities. As a result, they should be categorized as solely visual learners. This implies that visual learning methods need to be adjusted and customized to accommodate their unique needs.

According to Teplá et al. (2022), students at both middle and high schools have a favorable perception of the implementation of 3D models and animations. Their research demonstrates that the effective integration of visual aids streamlines abstract thinking and procedures and improves comprehension. Consequently, students may exhibit heightened interest in the subject matter and may even contemplate pursuing more studies in the field.

Because visual information is frequently the dominant medium for DHH children, MR has the potential to overcome social and educational barriers in overcoming learning-related constraints of deaf sign language users. Furthermore, MR may supply visuals and simulations to students, making the learning process easier and more entertaining (Yang et al., 2022).

Even with access to education, evidence shows that deaf children face numerous challenges, including a lack of natural language input and exposure from early literacy stages, a lack of teachers fluent in sign language, and a lack of a deaf-friendly learning environment aimed at yielding effective learning (WFD, 2016). These concerns place deaf children in a harmful educational situation by subjecting them to linguistic deprivation, which restricts their functioning by causing major deficiencies in social, intellectual, and psychological aspects of deaf and hard-of-hearing children's lives (WFD, 2016).

The increasing role of mixed reality in establishing a friendly sign language learning environment for teaching is central to our work. The key objective of this work is to educate and study Kazakh-Russian Sign Language (K-RSL) by showing translations of words in K-RSL and creating sentences utilizing mixed reality capabilities. Besides, we hope that expressing thoughts and ideas through the interaction progress (Signing Aloud) by the analogy with the Thinking Aloud task (Charters, 2003; Johnstone et al., 2006) and narrative components of the proposed learning activity may boost DHH children's creativity and provide us new ideas on how to improve the application.

As per Yin (2014), and Hollweck (2015) there exist multiple categories of case studies. We classify our current study as an exploratory user study, as we aim to determine how DHH students respond to mixed reality education and identify which stimuli face their needs and are potentially practical for learning.

The primary objective of our exploratory proposed study is to do controlled tests to identify the specific differences that must be taken into account while providing multimodal learning in an immersive 3D environment as opposed to a laptop. To observe how participants react to 3D objects as well as their overall perception in the immersive environment. Additionally, to assess DHH students' responses before and following the training session with a laptop, and a 3D application imported in mixed reality.

User experience(UX), as per the ISO 9241-210:2019 standard, refers to the subjective perception and defined as a set of emotions and reactions that arises from a consumer's interaction with a product, system, or service. It encompasses an individual's assessment of usefulness, user-friendliness, and effectiveness. Enhancing user experience holds significant importance for companies, designers, and creators during the process of creating and improving products. This is because a negative user experience can reduce the usage of the product and undermine any desired positive effects. The perception of user experience varies from person to person. Nevertheless, the components that constitute the user experience are factual and not influenced by personal opinion. The importance of UX in design is already widely recognised in the literature (Pucillo & Cascini, 2014; Bongard-Blanchy et al., 2015; Li & Hölttä-Otto, 2020).

User experience evaluation (UXE) or user experience assessment (UXA) is the systematic process of employing diverse methodologies, expertise, and instruments to ascertain an individual's perspective of a system (such as a product, service, non-commercial item, or a combination thereof) prior to, during, and subsequent to their interaction with it. Assessing user experience is an intricate undertaking because it is inherently subjective, reliant on context, and prone to change over time (Law et al., 2009). To effectively accomplish the objectives of a UXA study, the researcher must meticulously select the suitable dimensions, constructs, and methods, and customize the research to the particular field of interest.

One of the findings from the study mentioned in Forgas et al. (1988), is that children exhibit enhanced learning and retention when they are in a positive emotional state. In Tyng et al. (2017) empirical data has firmly proven that emotional events are retained in memory with greater clarity, accuracy, and longevity compared to neutral occurrences. Therefore, it is crucial for an augmented reality application to offer a pleasant user experience, or at the least, avoid creating a negative one. Hence, it was crucial for us to get insight into the extent to which students derived enjoyment from the 3D learning experience, their level of satisfaction during the engagement, and whether the experience caused discomfort leading to a deterioration in their mood.

To achieve this objective, we conducted a study utilizing cutting-edge MR technology and involving the DHH students as the application testers to investigate the potential, perception, and acceptability of mixed reality applications. This paper contributes to the field of human-computer interaction and multimodal interaction in Mixed Reality domains by establishing a design framework and a methodological protocol for the application and evaluation of MR systems of specific educational use.

The remaining part of the paper is organized as follows: the subsequent section of the paper (Section 2) presents the Backgrounds of areas such as the integration of Mixed Reality in Deaf Education and Participatory Design; the Section 3 outlines the conclusions drawn from a comparable prior study we taken into account; Methodology (Section 4); Results (Section 5); and Conclusions and Future Work (Section 6).

2 Background

2.1 Mixed reality in deaf education

Despite efforts to unveil the promise of mixed reality, its applications in sign language instruction have not yet been thoroughly investigated. Prior research assessed the effectiveness of different mixed reality wearable devices in assisting deaf instruction.

In their study, Adamo-Villani & Anasingaraju (2017) employed a holographic sign language avatar that was powered by the Unity 3D[4] game engine and the Meta 1[5] developer kit to improve the math knowledge and abilities of K-6 students. Their findings indicated that users perceived the system to be more entertaining and user-friendly than they initially expected. Additionally, it was observed that children derived pleasure from engaging in all of the activities and perceived the signing avatar as a facilitator in mitigating the challenges associated with comprehending the lesson.

Miller et al. (2017) assessed the comprehension of lectures among university students with hearing impairments using Google Glasses and The EPSON Moverio BT-200[6]. The qualitative feedback of the participants indicates that the glasses may be useful to mitigate the impact of visual field shifts during lectures, even though the quantitative data did not support the idea of higher understanding scores that had been expected by the authors.

Next, Parton (2017) conducted a pilot study with deaf upper elementary school students using Glass Vision 3D to explore the potential of such technology in vocabulary development. The findings revealed that in comparison to other gadgets (such as the iPad and iPhone), youngsters had a mostly favorable impression of Google Glass.

The effectiveness of mixed-reality-based interactive motion learning was more recently assessed by Shao et al. (2020) through a study involving 60 participants by contrasting the proposed system with a desktop-based non-interactive baseline. They used a ZED Mini[7] 3D stereo camera and the HTC VIVEPro[8]. Children's acquisition of American Sign Language (ASL) signs showed statistically significant advancements.

A limited number of endeavors to utilize an advanced holographic wearable device have been made for sign language research so far. Researchers have not treated the effects of learning sign language with virtual, augmented, or mixed reality tools in much detail. Recently, Yang et al. (2022) created a HoloLens[9]-powered MR application and carried out a mixed-subject design experiment with eight hearing volunteers who were proficient in ASL to assess its usefulness. Results cannot be applied to the DHH community because the study used hearing volunteers rather than DHH people. However, the findings suggest that careful attention should be paid to sign language

[4] https://unity.com/products/unity-engine

[5] https://wearables.com/products/meta-1-developer-kit

[6] https://epson.com/Clearance-Center/Wearables/Moverio-BT-200-Smart-Glasses-%28Developer-Version-Only%29/p/V11H560020

[7] https://www.stereolabs.com/zed-mini/

[8] https://www.vive.com/eu/product/vive-pro/

[9] https://learn.microsoft.com/en-us/hololens/hololens1-hardware

users' choices about the configurations and aesthetics of the MR application and its subparts, including a human-like avatar.

2.2 Participatory design

To establish a deaf-friendly and age-appropriate measurement protocol for the evaluation of virtual systems, it is paramount to involve the DHH children in the process of system development. This is normally accomplished through a user-centered design approach, often referred to as participatory design (PD) for developing, prototyping, and refining a system in collaboration with the target population (Spinuzzi, 2005). Participatory design, otherwise known in the SL research domain as community-engaged research (CEnR), has seen recognition in different areas of sign language research (Spinuzzi, 2005). However, their application seldom ensures the perspective of the Deaf is articulated decently through the use of proper data collection tools. Therefore, establishing a common protocol to be easily followed by the deaf or hard-of-hearing individuals as both researchers and participants should be prioritized.

3 Findings of previous study and current updates

We adhered to the fundamental principles of PD research, according to Spinuzzi (2005). Considering all the narrow points and drawbacks mentioned in the research outlined in Kydyrbekova et al. (2023) - we refer to Participatory Design (PD) as a component of the interface design (ID), along with the suggestions and desires expressed by its participants. This process involves several cycles of activities, as is typical of any ID, such as defining needs, generating specifications, producing several prototypes that match those criteria, and then having users and other stakeholders evaluate these prototypes.

Building upon this prior experience, we base on the limits and significant findings identified by Kydyrbekova et al. (2023) - we retained the solutions that yielded successful results: the translated informed consent with subtitles, the introductory video with instructions, the identical 3D model of the globe, the breadth of the lesson, and the concept of the sentence composition task as a quiz (see Figs. 1 and 6). Nevertheless, we abstained from utilizing signing avatars, which participants were supposed to evaluate, on this occasion - instead, we endeavored to design a lesson on animals by employing several modalities of sign interpretation and presentation, accompanied by a concise encyclopedic explanation (see Figs. 2 and 5).

In addition, we sought guidance from a proficient sign language interpreter and an instructor during the whole development process of the HoloLens 2 - powered application utilized in the present study, ensuring their endorsement. The process of designing the MR application was also iterative this time:

In-the-lab evaluation. Our first application implementation and its evaluation were conducted in-the-lab with a hearing child in the laboratory. The results of our observations revealed some inconveniences related to ergonomics. In particular, HoloLens 2 provides the option called "air tap" (pinching fingers in the air to select buttons located

Fig. 1 Quiz displayed in mixed reality, the task where students should complete the sentence by picking one appropriate option(sign): "... can swim at a speed up to 35 km per hour in water"

farther away) - the participating child reported facing troubles with such interaction the mixed reality, so this time we decided to use standard blue square buttons closer to participants still within the field of vision, so participant should not move head down right or down left to find them and tap more easily.

The in-the-lab setting has also proven another lack of ergonomics: processing several visual modalities together looks fine on the laptop screen (see Fig. 5). However, immersive space features require certain sizes for each element to provide proper visibility. Looking at all of them on the same plane simultaneously was challenging due to limited vision angle, so we decided to locate the main modalities in positions that mimic a triple-dressing table mirror (see Fig. 2) in the current experiment. While it is possible to track the activity of participants in the HoloLens 2 application using a laptop - there is a lag, and the absence of accompanying auditory signals poses an inconvenience and requires researchers to make assumptions regarding the current stage of the participants. Sound signals implemented into the current version as recommended after the previous study to indicate the completion of the instruction by the participants, triggered by specific events such as viewing the rotating globe or selecting an animal.

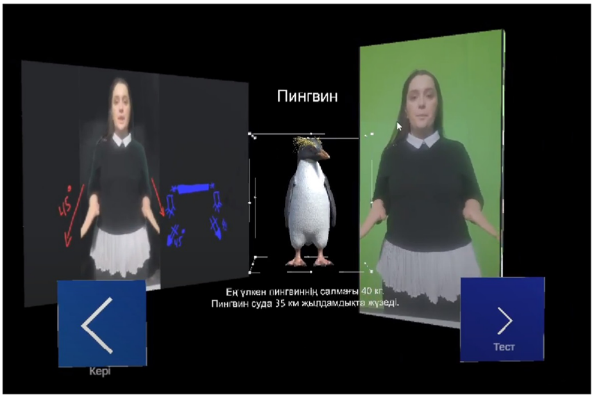

Fig. 2 A screenshot of the MR environment after the second iteration. "...The largest penguin can weigh up to 40 kilograms. Penguins can reach speeds of up to 35 km per hour while swimming in the water..."

In-the-wild evaluation. Since, in our case, lessons were meant to be shorter in time - we made the application for a standing position so a child could go around the spinning globe: velocity was adjusted to make it not too slow and annoying and not too fast for the participant may focus and decide which animal to select; so the experimental setup room should meet the system requirements and allow enough space for moving around during the interaction.

At the moments when the headset's battery charge was low, or the WiFi signal became weak researchers had to connect it to the laptop via wire. It was quite inconvenient for participants and bounded their area around the spinning globe. Researchers should also be attentive to safety measures if some wires are plugged into the HoloLens 2 headset.

4 Methodology

In their prior study, Kydyrbekova et al. (2023) aimed to obtain evaluations from deaf students regarding the signing performance of several avatars.

However, a significant obstacle encountered by researchers and sign language interpreters alike was the participants' limited or nonexistent proficiency in sign language, especially the youngest ones.

Some children used iconic signs or unique signs specific to their household environment and understandable solely to their immediate family members. Consequently, the sign language interpreters frequently encountered difficulties establishing rapport with participants.

Given that most individuals possessed a certain level of writing skills, it would be beneficial to demonstrate GLOSSes of concepts along with related images and signs to forge strong memory connections between them.

Despite possessing varying signing skills, students exhibited significant disparities in their levels of general competency.

Hence, we made the decision to change the paradigm of the application to focus on educating participants about famous animals, with the implementation of a Pre-test

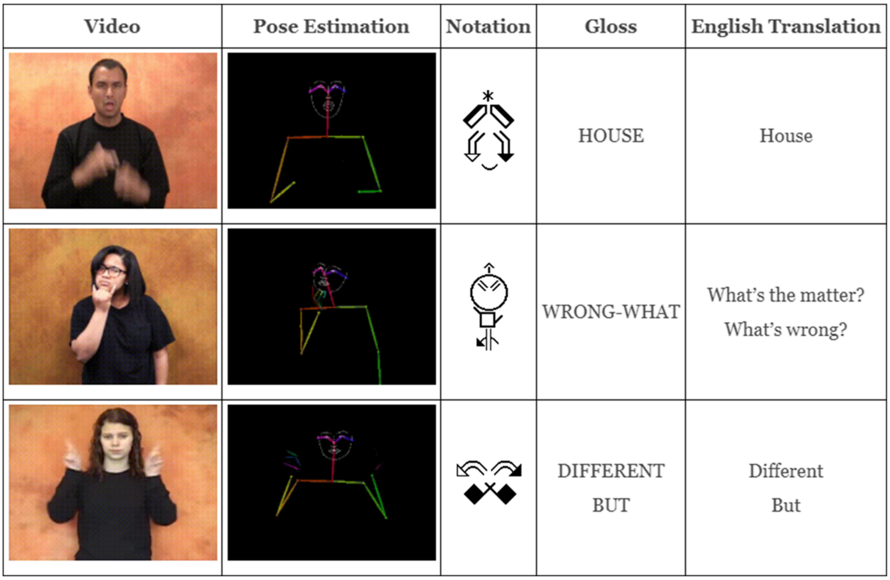

Fig. 3 Examples of SignWriting schemes shown in the third column ("Notation")

and Post-test experimental design to measure their awareness and skills before and after their interaction with the application.

4.1 Learning task

For the purpose of learning and memorizing signs for six different animals, we designed a learning activity. Children are immersed in a mixed reality setting wherein they have the opportunity to interact with virtual animals. These animals are presented as three-dimensional objects, accompanied by concise encyclopedic descriptions adapted to their age group. Additionally, the children were provided videos featuring a sign language interpreter who demonstrates the corresponding signs for specific animals and parallel step-by-step SignWriting schemes (Bouzid et al., 2016). Examples of SignWriting[10] are shown in Fig. 3. The decision to combine these modalities was initially influenced by the principles of Associative Vivid Imagery and Context Visualization (Johnson et al., 2020), and employing student-centered techniques (Mukhtoraliyevna et al., 2023) for educational purposes.

To the best of our understanding, mnemonic techniques have been employed in educational institutions and have demonstrated their efficacy over a considerable period of time, consistently eliciting engagement from students. In this study, the authors intended to examine DHH students' sign performance after interaction with an immersive environment that served as a mnemonic device.

The scope of this learning task encompasses the following areas:

10 https://www.sutton-signwriting.io/

- to test the impact of creating strong and mutual associations between several types of interpreting modalities (e.g., sign, SignWriting, written gloss, and brief written explanation) referring to the same concept as the learning and memorizing technique.
- gaining knowledge and comprehension of the meanings of words in either Kazakh or Russian;
- ensuring accurate spelling in Russian or Kazakh;
- developing the ability to recall and memorize the signs by constructing sentences using the words.

The utilization of three-dimensional representations in the teaching process has the potential to enhance participants' comprehension and retention of concepts. By providing students with the opportunity to visually interact with a 3D depiction of the subject matter, such as by examining it from multiple perspectives and interacting with its constituent elements, higher effective retention can be facilitated.

At this point, the learning task for comprehending the definition of a word and having a full understanding of it could be fulfilled.

The objective of achieving precise spelling was of secondary importance. We hope that associating the names of items and events in close proximity enhances the memory's ability to retrieve or acquire accurate spelling in the Kazakh or Russian language, depending on which language is the first for a pupil.

The primary objective of the learning task is to facilitate the acquisition and retention of sign language among children with hearing impairments. To this end, a variety of modalities were utilized, including a video of a human interpreter performing the sign, another video showcasing the same interpreter employing the SignWriting scheme for the sign, a concise encyclopedic written explanation, and GLOSS itself.

The final stage of interacting with the application involves a testing activity wherein the participants can assess their acquired knowledge. The participants had the freedom to construct phrases with the signs they had already acquired. Testing tasks were performed in the style of a quiz, wherein students were required to select an appropriate option in a drag-and-drop format to finish a phrase about animals that were presented with either a beginning or an end.

4.2 The proposed system

The mixed-reality system's development adhered to an iterative design methodology, which involved several iterations of design, implementation, and evaluation. This methodology facilitated the iterative refinement of the program through the incorporation of user feedback and the emergence of new insights. Every successive iteration played a role in the development of a design framework that enabled the construction of a durable and scalable application specifically designed to meet the requirements of children with hearing impairments. The step-by-step developments of the system were approved by a sign language educator. This collaboration facilitated a design foundation for an application that is both durable and scalable.

Microsoft HoloLens 2[11]

The absence of a barrier between the physical and virtual surroundings is a key advantage of augmented reality technologies compared to virtual reality for deaf individuals. The utility of employing HoloLens for individuals with hearing impairments, encompassing both children and adults, stems from the fact that in virtual reality settings (such as Meta Quest 2[12]), a deaf individual would be isolated from their actual surroundings, thereby forfeiting the ability to engage with an interpreter in the event of complications or inquiries. Under these circumstances, participants would be required to detach the full headset and initiate the procedure anew, which entails recalibration as well. More importantly, such logic also gives rise to safety concerns.

In order to provide an appropriate mixed reality (MR) experience, we opt HoloLens 2 headset. The selection of the Microsoft HoloLens 2 headgear was made as the designated platform for the application because it is prominent for its improved user engagement capabilities, and high-quality hand tracking, also, it has advanced software such as MRTK-Unity (MixedRealityToolkit)[13].

4.3 Proposed mixed reality application

At first, a participant was either sent to Laptops or HoloLens, where they learned about three animals they had chosen, after that, the participant would go to the other condition to learn about the rest three animals.

Unity There are four compatible engines to implement mixed reality with Hololens. According to Engine Overview [14], Unity supports all available features.

We have selected Unity as our prime developing platform since it was thoroughly tested (e.g. Adamo-Villani & Anasingaraju (2017) as mentioned above) and is compatible with various virtual, mixed, and augmented reality tools.

Moreover, Unity 2019.4 has a unique set of features that align with the capabilities of HoloLens 2, such as hand tracking, spatial mapping, and so on. Lastly, there was a strong community around Unity and HoloLens users, which guaranteed the stability of applications and the virtual environment.

Mixed Reality application (Condition 1)

Children navigated self-paced tutorials and advanced upon comprehension or sought simplified explanations from an interpreter. They then interacted with a virtual globe - The Main menu as 1st scene (see Fig. 4), selected animals from each continent and engaged with detailed 3D models accompanied by informative videos (Sign performance), SignWriting schemes as GIF, and textual content. Upon acquiring new knowledge, the student is prompted to proceed to the next scene, where a quiz will ensue, persisting until consistent and accurate responses are achieved. The participant's visual experience is observed by the researcher and the interpreter, who monitored the session through a laptop. For smooth sailing of the experiment, addi-

[11] https://www.microsoft.com/en-us/hololens/buy

[12] https://www.meta.com/quest/products/quest-2/

[13] https://learn.microsoft.com/en-us/windows/mixed-reality/mrtk-unity/mrtk3-overview/

[14] https://learn.microsoft.com/en-us/windows/mixed-reality/develop/choosing-an-engine?tabs=unity

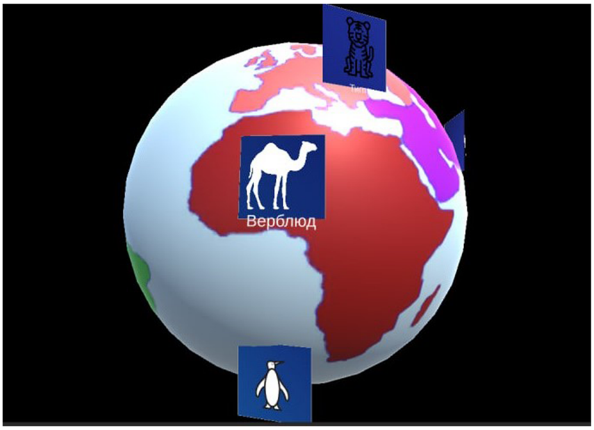

Fig. 4 The application's main menu is the spinning globe with buttons (cards) representing animals to learn about

tional audio tracks were included, which signal upon the user changing the scene, for cases such as if the laptop would turn off.

An intriguing observation arose regarding the manipulation of answer plates during quizzes. While some quickly grasped this aspect, others encountered challenges, leading to divergent outcomes. One of the main issues that participants struggled with was misunderstanding the mechanics behind interacting with MR plates and blocks.

Laptop demonstration (Condition 2)

We made the decision to employ a laptop as an alternative condition. The tasks remained identical (see Fig. 5); however, we did not include the feature of a rotating three-dimensional globe and three-dimensional models of animals. The tasks and

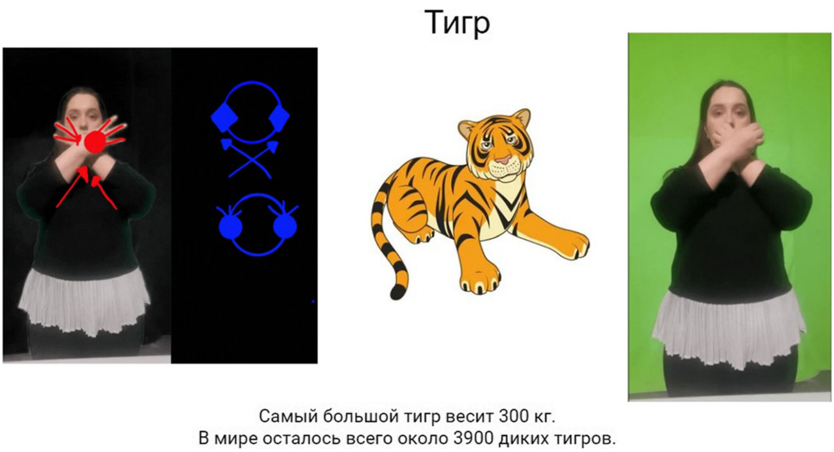

Fig. 5 "Tiger" concept explained on laptop. There are spelling on the top, image in the middle, short info provided below, GIF with SignWriting scheme on the left, and video performing the sign on the right. "...The largest tiger weighs 300 kilograms. There are only about 3,900 wild tigers left in the world..."

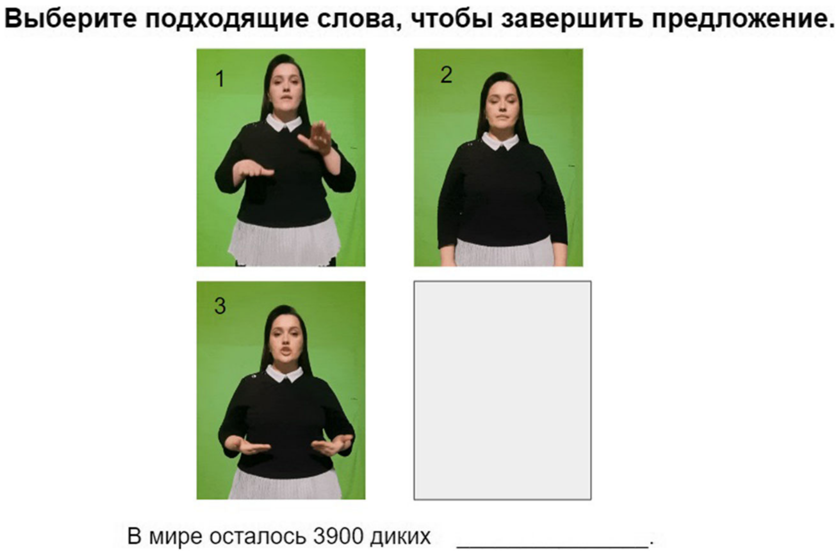

Fig. 6 Quiz displayed on laptop. There is the task where students should complete the sentence by picking one appropriate option(sign): "There are 3,900 wild ... left in the world"

quizzes mirrored that of a mixed-reality application integrated into the HoloLens 2 headset (see Figs. 1 and 6).

4.4 Evaluation

The mixed reality experiment was performed as a thematic lesson, wherein participants evaluated the application on site of a mainstream school that adheres to principles of inclusivity: the school has a specialized division offering study programs for children with special needs.

4.4.1 Recruitment

Before permission, this study underwent extensive ethical examination. The Institutional Research Ethics Committee (IREC) of Nazarbayev University approved it. All students and their parents received video translations of written child assent and informed consent forms in the local Kazakh-Russian sign language. The researchers provided a brief and basic description of the study's main purpose and the sequence of procedures required for the study.

4.4.2 Participants

Initially, we recruited 22 children, aged 9 to 14, from the closest mainstream secondary school that also promotes inclusive educational programs. These children expressed their willingness to participate in our research. Almost all those involved had sensorineural hearing loss in both ears, making their communication challenging without

Table 1 Demographics (participants' replies shown)

Sex	Age	City	SL(home)	Use of SL	SL started	Who taught SL	Deaf Relatives
M	9	Astana	Yes	2	from birth	Mom	No
M	10	City	No	4	school	-	No
M	11	Astana	Yes	3	school	Teacher	No
F	13	Astana	Yes	3	school	On my own	Yes
M	13	Qostanay	No	3	school	Teacher	No
M	12	Astana	Yes	3	school	Teacher	No
M	13	Astana	Yes	2	from birth	Mom	Yes
M	12	Taraz	No	3	school	Friends	Brother
F	14	Astana	No	3	-	Teacher	No
M	13	Astana	No	3	from birth	Sister	Yes
F	14	Astana	Yes	2	from birth	Mom and Dad	Yes
F	12	Astana	No	2	school	Teacher, friend	No
F	14	Astana	No	2	pre-school	Teacher	No
M	14	Kazakhstan	No	2	school	Friend	No
F	14	Astana	No	2	school	-	No
M	14	Astana	Yes	3	school	Teacher	Yes
M	13	Taraz born	No	1	school	Kids	No
F	13	Qyzylorda	No	2	school	Friends	No
M	12	Astana	No	2	pre-school	Teacher	No

sign language or a hearing aid device. Unfortunately, the parents of one participant had not given their permission, thus 14 boys and 7 girls participated.

Two participants had not filled in the demographics form. So demographic data are available for 19 participants. One girl reported that she learned sign language since her starting at school, while her twin brother noted that his sign language proficiency started from infancy, taught by his mother. A total of four participants reported sign language taught by a mother, mother, father, or a close relative.

They were also asked "Which of the following best describes your use of sign language?" and provided 4 options: 1) We only use sign language, 2) We use sign language and speak in equal amounts, 3) We only speak, and 4) We rely on our specific gestures. Their responses are reflected in the column "Use of SL" in Table 1.

The majority (14 out of 21) reported learning sign language starting at school or kindergarten from teachers and/or friends. All participants live and study in the capital city Astana at the moment of the study.

The observation can be made that the girl from Qyzylorda occasionally employed several vernacularisms in her communication, thereby enhancing knowledge of sign variants for the interpreters.

4.4.3 Requirements for the setup

The MR application integrated four distinct modalities for each concept (animal): written gloss, concise encyclopedic textual description, professional human sign language interpreter's performance of the corresponding sign, and SignWriting scheme. The primary objective of the lesson with the MR application was to teach several signs to deaf youngsters and establish strong associations between visual representation (3D model of the concept) and the sign, then try to evaluate their engagement and assess its user acceptance and perception.

The researchers allocated a distinct room that functioned as an extension of a conventional teaching space. One of the researchers on the team set up the space using a HoloLens 2 device and a laptop equipped with an MR program, enabling to monitoring of a mixed reality environment.

4.4.4 Assessment tool

In this iteration, we aimed to avoid monotony by refraining from employing various methods to evaluate mood simultaneously. We aimed to provide them with an uncomplicated instrument that required minimal cognitive effort to sustain an interactive and engaging ambiance. Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988) is a widely recognized scale for assessing mood or emotion. This scale consists of 20 items, divided into 10 items assessing positive affect (such as excitement and inspiration) and 10 items assessing negative affect (such as upset and fear). The rating for each item is determined using a five-point Likert Scale. This PANAS tool is used to quantify the extent to which the affect has been experienced during a specific time period. It was developed to assess affect across many contexts, including the current moment, the previous day, week, or year, or overall. Hence, the scale can be employed to assess state affect, dispositional or trait affect, temporal emotional fluctuations, or emotional reactions to stimuli. The PANAS has already acquired several modifications such as PANAS-X (Watson & Clark, 1994), PANAS-C (Laurent et al., 1999), and I-PANAS-SF (Thompson, 2007) during its existence.

The Positive and Negative Affect Schedule - Extended (PANAS-X) scale, developed by Watson & Clark (1994), is a measurement tool that assesses both positive affect (PA) and negative affect (NA). It also evaluates 11 primary affect dimensions, which are Fear, Sadness, Guilt, Hostility, Shyness, Fatigue, Surprise, Joviality, Self-assurance, Attentiveness, and Serenity. This instrument offers a total of eight distinct assessment durations. These timeframes span from momentary emotional states to intermediate mood states, dynamic attributes, and ultimately persistent personality traits. Unlike state-trait measures that only provide a binary timeframe, this instrument provides a more comprehensive range of options. In Ibrahim et al. (2021), PANAS-X is also used for pre mood assessment on -10 to +10 scale.

Regarding the implementations when dealing with children. A child version of the PANAS - the PANAS-C (Laurent et al., 1999), was based on psychometric and theoretical grounds and developed for self-report measuring of childhood anxiety and depression to differentiate anxiety from depression in youngsters. The PANAS-C assesses the frequency with which youngsters have experienced emotional states such as Excitement, Happyness, and so on over the course of the past few weeks. It consists of 30 items rated on a 1 to 5 Likert scale. Overall, the PANAS-C, like the adult PANAS, is a quite brief, beneficial tool that helps to differentiate anxiety from depression in youngsters.

Regarding examples of language adaptation, researchers in Casuso et al. (2016) translated the PANAS-C scale into Spanish to test it with Peruvian preadolescents. There is also PANAS-C-SF(short form) described in Ebesutani et al. (2012).

One of the really quick PANAS tools is the International Positive and Negative Affect Schedule Short-Form(I-PANAS-SF) (Thompson, 2007; Karim et al., 2011) is composed of two ten-item mood scales: one to measure positive affectivity and the other to measure negative affectivity.

Unfortunately, I-PANAS-SF contains items like Determined or Alert that still may need clarifications for deaf (solely visual) children. PANAS-C also contains some concepts which will take an amount of time to elaborate such as Miserable, Jittery, Delighted, Frightened. Besides, semantically similar items may have very similar outward form in sign language which will require more detailed explanations.

Recently, authors in Kaye & Schweiger (2023) made an attempt to select specific emojis that represent affective states and connect them with respective items from PANAS scales. Although authors conclude that the Emoji PANAS scale can be useful in minimizing language-related biases when expressing one's current emotional state, researchers advise exercising caution when using it to describe immediate mood, as it may not always yield consistent or accurate evaluations.

We aimed to devise a simple, straightforward yet effective, vivid, and comprehensible scale tailored for younger deaf pupils, particularly those in the solely visual realm. In light of these improvements and implementations to the PANAS scale and taking into account all the aforementioned advantages and disadvantages of such modified scales, we employed the scale depicted in Fig. 7 to assess the current iteration of the application prototype, which resembles the conventional 1 to 10 scale with a joviality range from very sad to excited.

4.4.5 The algorithm of the study

The study encompasses a sequence of events that take place before, during, and after the mixed reality interaction.

Prior to the interaction, the student arrives at the classroom and selects their preferred language, either Kazakh or Russian. They proceed to respond to demographic inquiries, fill out a pretest questionnaire, and complete a pre-interaction mood assessment.

To assess the extent to which children acquired knowledge from the session, we adopted the principles of Pre-test and Post-test quasi-experimental designs (Stratton, 2019; Maciejewski, 2020).

This design quantifies alterations by assessing participants prior to and following an intervention. The Pre-test assesses the dependent variable prior to the intervention,

Fig. 7 Emoji mood scale

whereas the Post-test evaluates it subsequent to the intervention. The disparity between the two measures is the alteration that transpired as a result of the intervention.

In our instance, the possible concerns of selection bias and maturation are not applicable due to the short time gap between conditions starting, typically less than 40 minutes. Additionally, the kids form a relatively homogeneous group as they are invited from similar classes and taught by the same teachers.

In our instance, the participants underwent a Pre-test before the interactions, a Post-test for Condition 1, and a Post-test for Condition 2 assessments.

The Pre-test included evaluations of mood (using the scale shown in Fig. 7) and knowledge related to six animals (see Fig. 8): comprehension and interpretation, accurate spelling of the concept, and correct demonstration of the sign.

The same evaluation procedure has been implemented for both Post-test assessments separately: once after a participant interacted with the first condition for three chosen animals - and later after a participant interacted with the second condition for the rest three animals.

During the first phase of engagement, the participant proceeds to don the HoloLens 2, initiates the application, undergoes a calibration process, watches the introduction to the application and instructions conveyed through sign language (see Fig. 9), and selects an animal from the rotating globe.

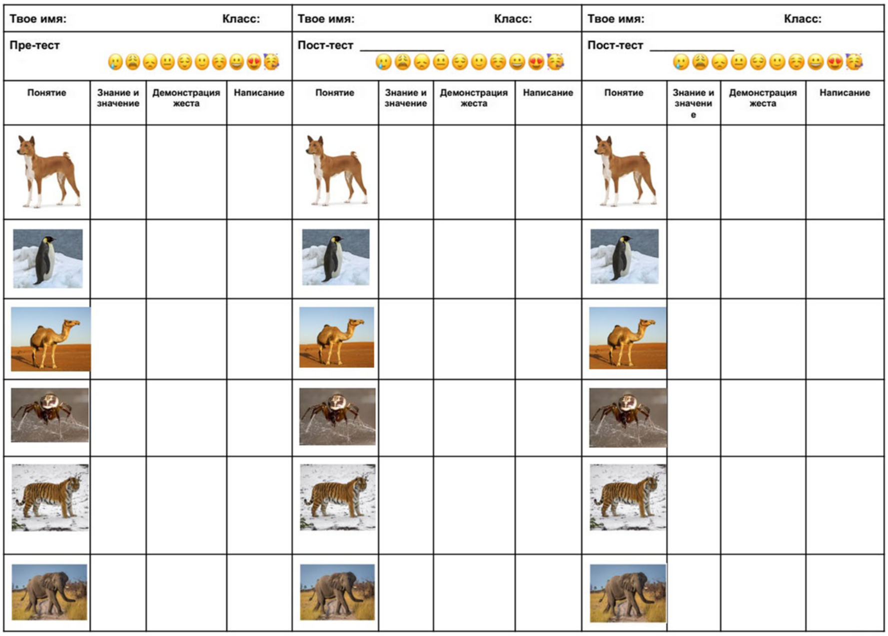

Fig. 8 Items of Pre and both Post-tests (after interactions with Condition 1 or Condition 2)

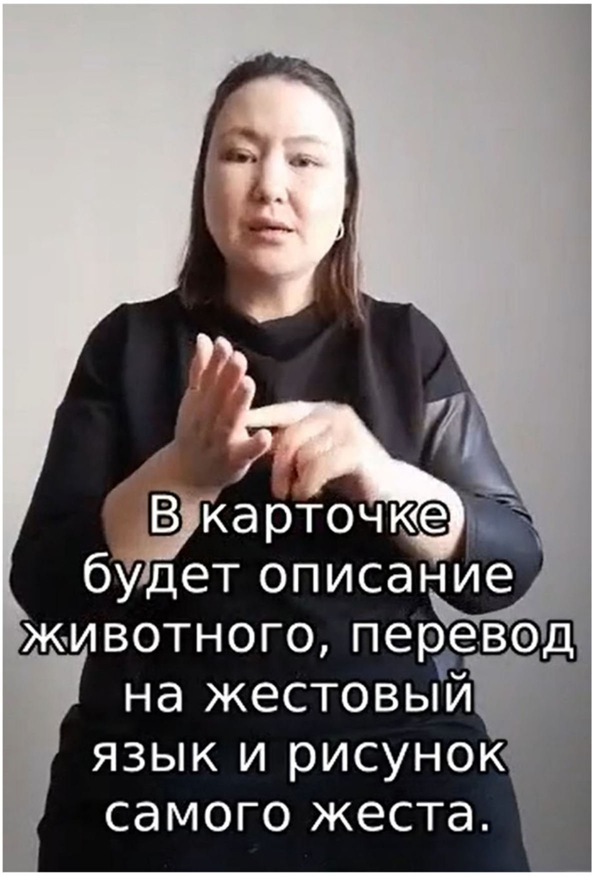

Fig. 9 A frame taken from the instruction video performed by an interpreter. Translation: "...In separate card you will see the description about chosen animal, translation into SL, and image of the sign itself..."

Subsequently, the selected animal is visually represented by an animated 3D model, accompanied by a written gloss, informative textual content elucidating its meaning, a video with a human interpreter performing the sign corresponding to the chosen animal, and animated SignWriting.

The participant engages in accessing species-related information and replicates the sign. After engaging with the 3D model, the user participates in a quiz whereby they are required to fill in phrases utilizing the designated animal sign. The computer assesses the sentences and assigns checkmarks for correct responses. Once a participant has coped with the task, the interaction is terminated and reverts to the main menu (the spinning globe menu) to select another animal.

Following the application interaction, the participant completes the Post-test with Post-interaction mood self-evaluation utilizing the same scale. Differences between mood evaluations before and after interaction with conditions are believed to reveal whether participants enjoyed the experience or not.

5 Results

During the experiment, a set of six different animal images (dog, penguin, camel, spider, tiger, and elephant) were presented. Participants were instructed to select three animals during Condition 1 (Laptop) and three other animals for Condition 2 (HoloLens 2). The order of the conditions was also varied.

We included Pre-tests to figure out whether were they familiar with concepts and signs before the study or not.

For Pre-tests, the participants were requested to write down the exact written designation of an animal (as GLOSS), perform the corresponding sign connected with the chosen animal, and thereafter share any knowledge they have regarding the characteristics and traits of the animal.

The participants also were instructed to perform all signs, write down all animals they remembered, and share any previously unknown insights they had acquired on animals following each experimental condition, as Post-tests.

About written expressions, it became apparent that some students possessed a certain degree of familiarity with accurate animal naming and previously encountered correct spelling, as seen by their utilization of the initial letter of the animal's name to denote the animal or the presence of spelling errors.

In instances when a participant successfully executed the appropriate official sign or a widely recognized variant, we recorded this as the accurate response and denoted it with a plus sign (+). In instances where a youngster performed a similar or personalized sign, such as the one used exclusively within their familial context, we denote it as "Tilda". In instances where a participant attempted but was unable to execute the sign accurately, we recorded it as a negative answer (-). If a participant failed to submit any information, we left the answer area blank (see tables provided in Appendix A). In addition, we similarly tested whether participants remembered the signs they encountered in the end: after interacting with both experimental conditions.

Some students, particularly those in the youngest age group, just bypassed reading and probably concentrated on animals and signs rather than reading the content. Due to this, only a few children could marginally increase their knowledge about the aforementioned species.

Out of all the participants, only two individuals enhanced their knowledge of animals by reading the descriptions included in the lesson. The remaining participants, upon completing the laptop and HoloLens lectures, just reiterated their prior knowledge similarly to their Pre-test responses.

In the subsequent week, the delayed Post-test revealed that each participant had successfully preserved virtually all of the six indications associated with the selected animals.

Children who did not participate could also perform these signs. It is assumed that the participants engaged in the act of sharing their mixed reality learning experiences with their peers. This ultimately contributed to the diffusion of knowledge among students who had not participated.

Mood evaluations (Huberty et al., 2021) were conducted at the beginning of the session with Pre-test questions set, and together with Post-tests of both conditions. Two participants could not self-evaluate their mood states all 3. We used a mood scale

Table 2 Mood shifts

	Pre-test	Laptop	HoloLens	Mood Change
Day 1	8	9	8	↓
	7	8	8	
	4	10	7	↓
	10	8	9	↑
	10	8	7	↓
	4	8	10	↑
	8	8	6	↓
Day 2	6	6	6	
	-	7	7	
	5	6	4	↓
	8	9	10	↑
	6	6	6	
	-	5	Refused	
	6	8	10	↑
Day 3	10	7	9	↑
	6	8	8	
	7	6	6	
	10	6	10	↑
	-	8	9	↑
	6	6	6	

with smiles (see Fig. 7) but converted participants' replies to a digital 1-10 scale for researchers' convenience (see Table 2).

On Day 2 and Day 3, most individuals observed either no change or a positive shift in mood across conditions. However, around half of the participants who participated in the experiment on Day 1 experienced a decrease in mood when exposed to mixed reality. Participants in the age range of 9-12 (excluding two kids who recently turned 13) who took part on the first day exhibited misconceptions regarding the usage of virtual buttons and drag-and-drop cards, which likely had an impact on their emotional state during the interaction.

The majority of participants on Days 2 and 3 were students between the ages of 13 and 14. Among the older students (Day 2 and Day 3), only one participant had a decline of 2 points in mood on the suggested scale (from 6 to 4). The other 4 cases with a lowered mood exhibited the following indicators: a decline from 9 to 8, a decrease from 10 to 7, a decrease from 8 to 7, and a decrease from 8 to 6.

There were a total of seven documented occurrences of mood enhancement. Two cases were identified among the participants: one showed an increase from 8 to 9, and the other showed an elevation from 8 to 10 on Day 1. The remaining five individuals had the following shifts: one from 9 to 10, one from 8 to 10, one from 7 to 9, one significant elevation from 6 to 10, and an increase from 8 to 9.

In other cases, the subjects' moods remained consistent across different conditions. The mixed reality application resulted in a higher frequency of mood enhancement, with a maximum improvement of 4 points on the suggested scale, compared to a maximal decline of 3 points.

Regarding the duration of student engagement with the theoretical component of the lesson, it was observed the majority of participants allocated a time frame ranging from 12 seconds to about one minute for each animal. This duration was considered sufficient for memorizing the sign, but it resulted in the omission of supplementary information and SignWriting schemes.

A total of seven students allocated a minimum of one minute to the observation of at least one animal. Among these participants, only three students spent more than one minute for two out of the three animals.

Thus, only two participants improved their general knowledge about offered animals. However, about a minute per animal for the whole theoretical part (watching the animal itself, animal description, SignWritings, isolated sign performance, etc.) was enough for only one student.

6 Conclusions and future work

According to feedback received from educators, the existing educational standards for deaf and hard-of-hearing children in Kazakhstan primarily emphasize the development of their socialization skills with the hearing majority. Consequently, the educational curriculum places significant emphasis on reading and writing abilities, broader conceptual knowledge, and teaching accurate sound pronunciation and mouth articulation techniques for effective communication with hearing individuals. It was unsurprising that the participants predominantly submitted written responses rather than providing sign performance during the Pre-test. Educators have observed a notable increase in students' inclination towards engaging in more rigorous sign language studies after their interaction with the suggested mixed reality application.

In continuation of our system and framework design, our next objective is to enhance mixed reality application by incorporating 3D signing characters, in conjunction with a human interpreter, to assess the relative perception of virtual sign language educators by students.

In our forthcoming research endeavors, we intend to direct our attention toward sign language, with the objective of developing a sign language learning framework beyond the mere memorization of isolated signs. Instead, we seek to offer a comprehensive learning experience through short tales, encyclopedic content, and historical essays, all presented in sign language.

It is recommended to incorporate questionnaires that encompass various aspects of participants' mixed reality experiences, including inquiries such as "Is this your first time using the Virtual Glasses Kit?" and "What is your overall perception of it?".

It is also important to include metrics such as Realism, Engagement, Immersion, Dizziness, Fatigue, and Eye strain, which can be assessed through a cybersickness questionnaire (Kourtesis et al., 2023; McCauley & Sharkey, 1992; Caserman et al., 2021).

While these questionnaires typically pertain to virtual reality (VR), it could be advantageous to incorporate certain questions from them into mixed reality research as well.

Cybersickness is thought to arise from a discrepancy between the visual perception of motion and the actual motion (or absence of motion) sensed by the inner ear. The issue tends to be worse in applications that replicate frequent and extensive motion. Furthermore, the problem may become exacerbated as the duration of the session increases.

The significance of the questions related to cybersickness is noteworthy, as educators have observed that kids they deal with may often have comorbid diseases such as epilepsy. Besides, they may experience symptoms such as headaches or vertigo, which can be related to inner ear issues.

In order to preclude children with such diagnoses from participating in studies including the utilization of virtual, mixed, or augmented reality glasses it is recommended to select and add cybersickness-related inquiries. It may also help determine whether participants who do not have significant comorbidities experienced discomfort with mixed reality to exclude them from future participation.

In our study, it was noted that a potential mnemonic strategy employed by certain children involved fingerspelling while briefly perusing the facts about the animals. It is likely that pupils unconsciously and automatically rely on techniques such as "muscle memory" or "finger" mnemonics (Mukhtoraliyevna et al., 2023) to memorize descriptions, similar to the way one learns a new piano piece.

We found that in almost half of the instances, there was no change in students' moods when transitioning from interacting with the laptop to the mixed environment, and vice versa. In the present study, there was a slightly higher incidence of mood enhancement following training in an immersive setting, and the maximal enhancement amplitude was wide compared to the cases of mood deterioration. Nevertheless, we acknowledge that the application needs certain modifications. It is advisable to conduct a follow-up study with a larger sample size since the findings from the study conducted with a relatively small group cannot be extrapolated to all DHH students in Kazakhstan, the CIS, or other regions. It is also necessary to understand that children, like adults, have different emotionalities, which can be of a different nature (for example, the emotional lability of a participant (Van Liefferinge et al., 2018; Sobanski et al., 2010)), and this must be taken into account when there is a sharp improvement or deterioration after the interaction. It may also be important to enlarge the scale (for example, from 0 to 20, or -10 to +10). In addition, we advocate the inclusion of several comparable ranges in the mood and experience evaluation, which should be presented as a distinct section, mirroring the structure of the GodSpeed (Bartneck et al., 2009) questionnaire.

We should also probably use distinctive arrows and colored frames to make the SignWriting schemes and descriptions more noticeable. It should potentially assist in directing the participants' attention to cover all provided material and ensure they don't miss anything and might ensure that everyone gets the same and that the session runs smoothly.

SignWriting schemes were not intuitive and friendly, especially for the youngest participants. Probably, SignWriting should be introduced specifically for complex signs related to college or bachelor's degree terminology, and demand explicit and slow performance to be memorized.

Appendix A Respondents' Pre-test and both post-test answers (tables below)

Table 3 The particicpants' answers for Pre-test, Condition 1 Post-test, and Condition 2 Post-test - Part 1

#	Pre-sest animal	write	sign	meaning	Post-test writing	condition sign	**Condition 1** meaning	Post-test writing	condition sign	**Condition 2** meaning
1	Pre-set				Post-test	condition	**HoloLens**	Post-test	condition	**Laptop**
	animal	write	sign	meaning	writing	sign	meaning	writing	sign	meaning
	dog	+	-	own	~	+			+	
	penguin	-	-	own	-	+			+	
	camel	-	-	own	-	+			+	
	spider	~	+	own	-	-			+	
	tiger	-	-	-					+	
	elephant	~	-	own					+	
2	Pre-sest				Post-test	condition	**HoloLens**	Post-test	condition	**Laptop**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	~	-	own		-				
	penguin	-	-						+	
	camel	-	-	own				~	+	
	spider	-	-	own				~	+	
	tiger	-	-			+				
	elephant	-	-			+				
3	Pre-sest				Post-test	condition	**HoloLens**	Post-test	condition	**Laptop**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	-	own		+			+	
	penguin		-			+			+	
	camel	+	-	own		+			+	
	spider	+	-	own					+	
	tiger		-	own					+	
	elephant	+	-	own					+	
4	Pre-sest				Post-test	condition	**HoloLens**	Post-test	condition	**Laptop**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	-	own	+	-	+(own)		+	
	penguin	-	-	-					+	
	camel	~	-	-	+	+	+(own)		+	

Table 3 continued

#	Pre-sest animal	write	sign	meaning	Post-test writing	condition sign	**Condition 1** meaning	Post-test writing	condition sign	**Condition 2** meaning
	spider	-	-	-	+	+	+(own)		+	
	tiger	-	-	-					+	
	elephant	+	+	own					+	
5	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	-	-		+	+(own)		+	+(own)
	penguin		-	-		+	+(own)		+	+(own)
	camel		-	own					+	+(own)
	spider	+	-	own					+	+(own)
	tiger		-	own		+	+(own)		+	+(own)
	elephant		-	own					+	+(own)
6	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	-	own	+	+	+(own)	+	+	+(own)
	penguin	-	-	own	+	+	+(own)	+	+	+(own)
	camel	+	-	own				+	+	+(own)
	spider	+	-	own				+	+	+(own)
	tiger	-	-	own	-	+	+(own)	~	+	+(own)
	elephant	+	-	own				+	+	+(own)
7	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	+	own				+		
	penguin	-	-	own	-	+	+(own)		+	gain
	camel		-	own	+	+	gain		+	
	spider	~	~	own	+	+	gain		+	
	tiger		+	-					+	
	elephant	+	+	own				+	+	

Table 4 The particicpants’ answers for Pre-test, Condition 1 Post-test, and Condition 2 Post-test - Part 2

#	Pre-sest animal	write	sign	meaning	Post-test writing	condition sign	**Condition 1** meaning	Post-test writing	condition sign	**Condition 2** meaning
8	Pre-sest				Post-test	condition	**HoloLens**	Post-test	condition	**Laptop**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	-	own	+			+	+	
	penguin	-	-	-					+	
	camel	+	-	-	+	+		+	+	
	spider	+	-	own				+	+	
	tiger	-	-	-	+	+		+	+	
	elephant	-	-	own				+	+	
9	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	+	own		+				
	penguin	-	+	own						
	camel	+	+	own						
	spider	-	+	own		+				
	tiger	-	-	-		+				
	elephant	+	+	own						
Day 2										
10	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	-	own	+	+	+(own)	+	+	+(own)
	penguin	-	-	-	+	+	+(own)	+	+	+(own)
	camel	+	-	own				+	+	+(own)
	spider	+	-	own				+	+	+(own)
	tiger	lion	-	own	+	+	+(own)	-	-	-
	elephant	+	-	own				-	-	-
11	Pre-sest				Post-test	condition	**HoloLens**	Post-test	condition	**Laptop**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	-		+	+	gain			
	penguin	+	-		+	+	gain			
	camel	+	-					+	+	gain
	spider	+	-		+	+	gain			
	tiger	+	-					+	+	gain
	elephant	+	-					+	+	gain
12	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	+	own	+	+	+(own)			
	penguin	-	+	own	+	+	+(own)			
	camel	+	-	own	-	-		+	-	+(own)
	spider	+	~	own	+	+		+	+	+(own)

Table 4 continued

#	Pre-sest animal	write	sign	meaning	Post-test writing	condition sign	**Condition 1** meaning	Post-test writing	condition sign	**Condition 2** meaning
	tiger	+	~	own	+	+	+(own)			
	elephant	+	~	own	+	+		+	+	+(own)
13	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	-	own	+	+	+(own)			
	penguin	-	+	own	+	+	+(own)			
	camel	~	-	own				+	+	+(own)
	spider	+	~	own				+	+	+(own)
	tiger	+	~	own	+	+	+(own)			
	elephant	+	-	-				+	+	+(own)
14	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**refused**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	+	-	+	+	+(own)			
	penguin	-	-	-	+	+	+(own)			
	camel	-	-	-						
	spider	+	+	own						
	tiger	+	+	own	+	+	+(own)			
	elephant	+	+	own						

Table 5 The particicpants' answers for Pre-test, Condition 1 Post-test, and Condition 2 Post-test - Part 3

#	Pre-sest animal	write	sign	meaning	Post-test writing	condition sign	**Condition 1** meaning	Post-test writing	condition sign	**Condition 2** meaning
15	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+			-		-	+	+	+(own)
	penguin		+					+	+	+(own)
	camel				-			+	+	+(own)
	spider	+			-			+	+	+(own)
	tiger	+						+	+	+(own)
	elephant	+	+					+	+	+(own)
Day 3										
16	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog					+		+	∼	
	penguin					+		tiger	+	
	camel	+	+	own		+		+	∼	+(own)
	spider					∼		+	+	+(own)
	tiger					+		-	∼	
	elephant					∼	+(own)	+	+	
17	Pre-sest				Post-test	condition	**HoloLens**	Post-test	condition	**Laptop**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog		∼	own	+	+				
	penguin		∼	own					+	+(own)
	camel		∼		-	+	∼			
	spider		∼	own	-	+	+(own)			
	tiger		∼						+	+(own)
	elephant		+						+	
18	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+		own	+	∼	+(own)			
	penguin			own		∼	+(own)			
	camel	∼		own				+	+	+(own)
	spider			own				∼	+	+(own)
	tiger	-		own	-	∼	+(own)			
	elephant	∼		own				+	+	+(own)
19	Pre-sest				Post-test	condition	**HoloLens**	Post-test	condition	**Laptop**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+	∼	own				+	+	+(own)
	penguin	-	∼	own	+	∼ close	+(own)			

Table 5 continued

#	Pre-sest animal	write	sign	meaning	Post-test writing	condition sign	**Condition 1** meaning	Post-test writing	condition sign	**Condition 2** meaning
	camel	-	~	own	-	-	+(own)			
	spider	-	~	own				~ close	+	+(own)
	tiger	-	~	own						
	elephant	-	+	own	+	-	+(own)	-	+	+(own)
20	Pre-sest				Post-test	condition	**HoloLens**	Post-test	condition	**Laptop**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog	+			+	+	+(own)			
	penguin				~	+	+(own)			
	camel				~	+	+(own)			
	spider							~	+	
	tiger			own					+	+(own)
	elephant			own				+	+	+(own)
21	Pre-sest				Post-test	condition	**Laptop**	Post-test	condition	**HoloLens**
	animal	write	sign	meaning	write	sign	meaning	write	sign	meaning
	dog		+	own	+		+(own)			
	penguin									
	camel		+		+	+				
	spider		+					+	+	+(own)
	tiger		+					+	-	+(own)
	elephant		+					+	+	+(own)

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Declarations

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References

Adamo-Villani, N., & Anasingaraju, S. (2017). Holographic signing avatars for deaf education. *E-learning, E-education, and Online Training: Third International Conference, eLEOT 2016, Dublin, Ireland, August 31–September 2, 2016, revised selected papers* (pp. 54–61).

Arici, F., Yildirim, P., Caliklar, Ş, & Yilmaz, R. M. (2019). Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis. *Computers & Education, 142*, 103647.

Bacca Acosta, J. L., Baldiris Navarro, S. M., Fabregat Gesa, R., Graf, S., et al. (2014). Augmented reality trends in education: a systematic review of research and applications. *Journal of Educational Technology and Society, 17*(4), 133–149.

Bartneck, C., Kulić, D., Croft, E., & Zoghbi, S. (2009). Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. *International journal of social robotics, 1*(1), 71–81.

Biffi, E.Z., & Woodbury, M. (2018). Interactive Multimedia Learning vs. Traditional Learning in Optometry: a Randomized Trial, B-scan Example. *Optometric Education*, *44*(2), 1–7.

Bongard-Blanchy, K., Bouchard, C., Bonnardel, N., Lockner, D., & Aoussat, A. (2015). User experience dimensions in product design: a consolidation of what academic researchers know and what design practitioners do. *Journal of Design Research, 13*(2), 107–124.

Bouzid, Y., Jemni, M., et al. (2016). The effect of avatar technology on sign writing vocabularies acquisition for deaf learners. In: *2016 IEEE 16th International Conference on Advanced Learning Technologies (icalt)* (pp. 441–445).

Caserman, P., Garcia-Agundez, A., Gámez Zerban, A., & Göbel, S. (2021). Cybersickness in current-generation virtual reality head-mounted displays: systematic review and outlook. *Virtual Reality, 25*(4), 1153–1170.

Casuso, L., Gargurevich, R., Van den Noortgate, W., Van den Bergh, O. (2016). Psychometric properties of the positive and negative affect schedule for children (panas-c) in peru. *Revista Interamericana de Psicologia/Interamerican Journal of Psychology*, *50*(2).

Charters, E. (2003). The use of think-aloud methods in qualitative research an introduction to think-aloud methods. *Brock Education Journal*, *12*(2), ,

Diegmann, P., Schmidt-Kraepelin, M., Eynden, S., & Basten, D. (2015). Benefits of Augmented Reality in Educational Environments-A Systematic Literature Review. *Benefits, 3*, 6–2015.

Donally, J. (2022). *Learning transported: Augmented, virtual and mixed reality for all classrooms*. 2111, Wilson Boulevard, Suite 300,Arlington, VA 22201, USA: International Society for Technology in Education.

Ebesutani, C., Regan, J., Smith, A., Reise, S., Higa-McMillan, C., Chorpita, B.F. (2012). Positive and negative affect schedule for children–short form. *Journal of Psychopathology and Behavioral Assessment*.

Forgas, J. P., Burnham, D. K., & Trimboli, C. (1988). Mood, memory, and social judgments in children. *Journal of Personality and Social Psychology, 54*(4), 697.

Hennerley, J., Dickinson, M., Jiang, M. (2017). Augmented reality enhanced human robot interaction for social robots as e-learning companions. *Proceedings of the 31st British Computer Society Human Computer Interaction Conference* (pp. 1–6).

Hollweck, T. (2015). Robert K. Yin.(2014). case study research design and methods. *Canadian Journal of Program Evaluation*, *30*(1), 108–110.
Huberty, J., Green, J., Puzia, M., & Stecher, C. (2021). Evaluation of mood check-in feature for participation in meditation mobile app users: retrospective longitudinal analysis. *JMIR mHealth and uHealth, 9*(4), e27106.
Ibrahim, A., Ali, H., Zghoul, A., & Jaradat, S. (2021). Mood state and human evaluation of the thermal environment using virtual settings. *Indoor and Built Environment, 30*(1), 70–86.
Johnson, T., Stanko, K., & Jefferson, S. (2020). Associative Imagery as a Strategy to Improve Destination Memory in Younger and Older Adults. *Innovation in Aging, 4*(Suppl 1), 361.
Johnstone, C.J., Bottsford-Miller, N.A., & Thompson, S.J. (2006). Using the Think Aloud Method (Cognitive Labs) to Evaluate Test Design for Students with Disabilities and English Language Learners. Technical Report 44. *National Center on Educational Outcomes, University of Minnesota*.
Karim, J., Weisz, R., & Rehman, S. U. (2011). International positive and negative affect schedule short-form (i-panas-sf): Testing for factorial invariance across cultures. *Procedia-Social and Behavioral Sciences, 15*, 2016–2022.
Kaye, L. K., & Schweiger, C. R. (2023). Are emoji valid indicators of in-the-moment mood? *Computers in Human Behavior, 148*, 107916.
Kim, R. S., Seitz, A. R., & Shams, L. (2008). Benefits of stimulus congruency for multisensory facilitation of visual learning. *PLoS One, 3*(1), e1532.
Kourtesis, P., Linnell, J., Amir, R., Argelaguet, F., & MacPherson, S.E. (2023). Cybersickness in virtual reality questionnaire (csq-vr): A validation and comparison against ssq and vrsq. *Virtual worlds* (Vol. 2, pp. 16–35).
Kydyrbekova, A., Kenzhekhan, A., Omirbayev, S., Oralbayeva, N., Imashev, A., & Sandygulova, A. (2023). Interaction Design of the Mixed Reality Application for Deaf Children. *Proceedings of the 6th International Workshop on Virtual, Augmented, and Mixed-Reality for Human-Robot Interactions at HRI 2023 (HRI 2023), Stockholm, Sweden.*
Laurent, J., Catanzaro, S. J., Joiner, T. E., Jr., Rudolph, K. D., Potter, K. I., Lambert, S., & Gathright, T. (1999). A measure of positive and negative affect for children: scale development and preliminary validation. *Psychological assessment, 11*(3), 326.
Law, E.L.-C., Roto, V., Hassenzahl, M., Vermeeren, A.P., Kort, J. (2009). Understanding, scoping and defining user experience: a survey approach. *Proceedings of the sigchi conference on human factors in computing systems* (pp. 719–728).
Li, J., & Hölttä-Otto, K. (2020). The influence of designers' cultural differences on the empathic accuracy of user understanding. *The design journal, 23*(5), 779–796.
Liu, S., Toreini, P., & Maedche, A. (2022). Designing Gaze-Aware Attention Feedback for Learning in Mixed Reality. *Proceedings of Mensch und Computer 2022* (pp. 503–508).
Maciejewski, M. L. (2020). *Quasi-experimental design. Biostatistics & Epidemiology, 4*(1), 38–47.
Mateu, J., Lasala, M. J., & Alamán, X. (2014). Virtualtouch: a tool for developing mixed reality educational applications and an example of use for inclusive education. *International journal of human-computer interaction, 30*(10), 815–828.
McCauley, M.E., & Sharkey, T.J. (1992). Cybersickness: Perception of self-motion in virtual environments. *Presence: Teleoperators & Virtual Environments*, *1*(3), 311–318.
Miller, A., Malasig, J., Castro, B., Hanson, V.L., Nicolau, H., & Brandão, A. (2017). The use of smart glasses for lecture comprehension by deaf and hard of hearing students. *Proceedings of the 2017 chi conference extended abstracts on human factors in computing systems* (pp. 1909–1915).
Mukhtoraliyevna, Z. S., et al. (2023). Mnemotechnique Techniques in Pedagogical Work with Primary School Students. *Texas Journal of Philology, Culture and History, 17*, 77–84.
Parton, B. S. (2017). Glass vision 3D: digital discovery for the deaf. *TechTrends, 61*, 141–146.
Pucillo, F., & Cascini, G. (2014). A framework for user experience, needs and affordances. *Design studies, 35*(2), 160–179.
Radu, I., Hv, V., & Schneider, B. (2021). Unequal impacts of augmented reality on learning and collaboration during robot programming with peers. *Proceedings of the ACM on Human-Computer Interaction, 4*(CSCW3), 1–23.
Shao, Q., Sniffen, A., Blanchet, J., Hillis, M. E., Shi, X., Haris, T. K., et al. (2020). Teaching american sign language in mixed reality. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 4*(4), 1–27.

Shiue, Y.-M., Hsu, Y.-C., Sheng, M.-H., & Lan, C.-H. (2019). Impact of an augmented reality system on students' learning performance for a health education course. *International Journal of Management, Economics and Social Sciences (IJMESS)*, *8*(3), 195–204.

Sobanski, E., Banaschewski, T., Asherson, P., Buitelaar, J., Chen, W., Franke, B., et al. (2010). Emotional lability in children and adolescents with attention deficit/hyperactivity disorder (adhd): clinical correlates and familial prevalence. *Journal of Child Psychology and Psychiatry, 51*(8), 915–923.

Spinuzzi, C. (2005). The methodology of participatory design. *Technical communication, 52*(2), 163–174.

Stratton, S. J. (2019). Quasi-experimental design (pre-test and post-test studies) in prehospital and disaster research. *Prehospital and disaster medicine, 34*(6), 573–574.

Teplá, M., Teplý, P., & Šmejkal, P. (2022). Influence of 3D models and animations on students in natural subjects. *International Journal of STEM Education, 9*(1), 65.

Thompson, E. R. (2007). Development and validation of an internationally reliable short-form of the positive and negative affect schedule (panas). *Journal of cross-cultural psychology, 38*(2), 227–242.

Tyng, C.M., Amin, H.U., Saad, M.N., Malik, A.S. (2017). The influences of emotion on learning and memory. *Frontiers in psychology*, 1454.

Van Liefferinge, D., Sonuga-Barke, E., Danckaerts, M., Fayn, K., Van Broeck, N., & Van der Oord, S. (2018). Measuring child and adolescent emotional lability: How do questionnaire-based ratings relate to experienced and observed emotion in everyday life and experimental settings? *International journal of methods in psychiatric research, 27*(3), e1720.

Vazquez, C.D., Nyati, A.A., Luh, A., Fu, M., Aikawa, T., & Maes, P. (2017). Serendipitous language learning in mixed reality. *Proceedings of the 2017 chi conference extended abstracts on human factors in computing systems* (pp. 2172–2179).

Watson, D., & Clark, L.A. (1994). The panas-x: Manual for the positive and negative affect schedule-expanded form.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the panas scales. *Journal of personality and social psychology, 54*(6), 1063.

WFD. (2016). 7 september 2016: WFD position paper on the language rights of deaf children. (https://wfdeaf.org/news/resources/wfd-position-paper-on-the-language-rights-of-deaf-children-7-september-2016/)

Yang, F.-C., Mousas, C., & Adamo, N. (2022). Holographic sign language avatar interpreter: A user interaction study in a mixed reality classroom. *Computer Animation and Virtual Worlds, 33*(3–4), e2082.

Yin, R. K. (2014). *Case study research: Design and methods (applied social research methods)*. Thousand Oaks, CA: Sage publications.

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