Inclusive AR-games for Education of Deaf Children: Challenges and Opportunities

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Abstract: Game-based learning has had a rapid development in the 21st century, attracting an increasing audience. However, inclusion of all is still not a reality in society, with accessibility for deaf and hard of hearing children as a remaining challenge. To be excluded from learning due to communication barriers can have severe consequences for further studies and work. Based on previous research Augmented Reality (AR) games can be joyful learning tools that include activities with different sign languages, but AR based learning games for deaf and hard of hearing lack research. This paper aims to present opportunities and challenges of designing inclusive AR games for education of deaf children. Methods involved conducting a scoping review of previous studies about AR for deaf people. Experts were involved as co-authors for in-depth understanding of sign languages and challenges for deaf people. A set of AR input and output techniques were analysed for appropriateness, and various AR based game mechanics were compared. Results indicate that inclusive AR gameplay for deaf people could be built on AR based image and object tracking, complemented with sign recognition. These technologies provide input from the user and the real-world environment typically via the camera to the app. Scene tracking and GPS can be used for location-based game mechanics. Output to the user can be done via local signed videos ideally, but also with images and animations. Moreover, a civic intelligence approach can be applied to overcome many of the challenges that have been identified in five dimensions for inclusion of deaf people i.e., cultural, educational, psycho-social, semantic, and multimodal. The input from trusted, educated signers and teachers can enable the connection between real world objects and signed videos to provide explanations of concepts. The conclusion is that the development of an inclusive, multi-language AR game for deaf people needs to be carried out as an international collaboration, addressing all five dimensions.

Keywords: Deaf, Sign language, Game-based learning, Augmented reality, Accessibility

1. Introduction

The development of games and game-based learning in the 21st century has been a fast and broad process. With the two categories of hardcore games and casual games combined digital games are attracting a large part of the population (Juul, 2010). However, inclusion of all is still not a reality in contemporary society, with accessibility for deaf and hard-of-hearing (DHH) people as one of the remaining challenges (Costello, Lambert & Kern, 2019). To be excluded from learning due to communication barriers can have severe consequences for deaf persons, for further studies and work. According to the principle of 'Education for All', DHH students should not be excluded from mainstream education (Ibrahim, Alias & Nordin, 2016), and with the ongoing development educational games are gradually being integrated into mainstream education.

In order to create learning games accessible for DHH people, game developers should make an effort to present the content of acoustic inputs in a deaf-friendly visual modality. Two possible solutions that might be useful to overcome language and communication barriers are the implementation of written text and sign language translation into the game design. Both of them are accessible to DHH people in that they can be perceived through an intact sensory modality (i.e., sight) and do not rely on the acoustic modality. However, as extensively discussed in Mantovan et al (2016), an important difference should be highlighted.

A written text is a visual representation of an auditorily-based language system, which by nature requires hearing to trigger spontaneous language acquisition. Overall, the competence level in a spoken language does not appear homogeneous within the DHH population, with several factors being involved: degree of hearing loss,

onset age, use of hearing aids or cochlear implants and so on (Swisher 1989). Despite being (apparently) fully accessible to DHH people, written texts pose a challenge to many of them who do not have a native competence in the lexicon and grammar of the spoken language. This is even more true for DHH children who are still in the process of language learning and are likely to struggle with text comprehension more than adults. Also, inputs in written form do not transmit information provided by intonation and other prosodic features, which may result in a sort of emotional detachment from the contents of the game.

On the other hand, sign languages are full-fledged natural languages expressed in the visual modality. A common misconception is that sign languages are somehow parasitic to spoken languages, but this is not the case as languages in the two modalities have independently emerged and evolved through the spontaneous interaction of the members of their communities. More than sixty years of scientific research on sign languages have demonstrated that they display the same level of linguistic complexity that has been observed in spoken languages (a.o. Sandler & Lillo-Martin 2006; Brentari 2010). Abstract linguistic structures are realised through two manual articulators (i.e., the hands) and a number of non-manual markers including facial expressions, movements of the head and shoulders. Because of their visual nature, sign languages under appropriate exposure can be fully acquired by DHH individuals in an effortless and spontaneous way. Sign language inputs may be integrated in a learning game basically in two ways: through video-recordings of human signers or the manipulation of virtual signing characters.

Augmented reality (AR) games provide opportunities for designing joyful learning in educational settings with different sign languages for DHH children, but there are also several challenges. Many studies have been conducted about AR games for learning and for DHH people but studies about AR-based educational games for DHH and especially deaf children seems to be a gap in current research or is at least less researched. This paper aims to present challenges and opportunities for the design and development of inclusive mobile AR-games for education of DHH children based upon current research.

2. Methods

Design science research (DSR) combines design and scientific study of artefacts to enable people to overcome challenges or realise opportunities (Johannesson & Perjons, 2014). While this study does not create such an artefact directly, the more long-term purpose is to enable a development of inclusive educational AR-games for DHH children. The DSR method framework by (Ibid.) includes several activities where this paper focuses on explicating problems. A scoping review of previous studies about AR for DHH people was conducted to create an overview of the selected area as described by (Munn et al., 2018). Scoping reviews have been recommended as an appropriate approach to explore a complex or heterogeneous field of knowledge (Mays, Roberts & Popay, 2001; Pham et al., 2014), and relevant for studies with the purpose of identifying knowledge gaps and clarifying concepts. Scoping review offers a method to gather key concepts in a specific research field, and to identify the main sources for future work. (Munn et al., 2018).

Searches were done during December 2021 to May 2022 using Google Scholar. The main query was created with *allintitle: "augmented reality" +deaf* with no limitations of publication year to find studies specifically for deaf. Also, by only including papers with the search string in the title ensured that each paper had a clear focus on these search terms. To widen the scope for related research in an extended search, the +deaf term was replaced by +accessibility, +accessible, +disabilities, +disability, +impairment, +impairments, +impaired in individual searches. From the extended search, only papers that focused on DHH people were included. Further exclusion criteria were that papers must be published research. Moreover, to better understand the target group of DHH players, involving experts in sign language as well as about education for DHH people as co-authors was required.

Also, a set of potential AR input and output techniques were analysed for appropriateness based on a unified method for universally accessible games (Grammenos, Savidis & Stephanidis, 2007). The appropriateness analysis compares potential input/output options with user characteristics, and evaluates if each option is ideal, appropriate, could be used, inappropriate or neutral.

3. Findings and Discussion

3.1 Scoping review of AR for DHH people

From the scoping review it was found that Augmented reality for DHH people has been recently explored in studies for various purposes. Quintero et al (2019) conducted a systematic review of AR for inclusive education,

with some studies about DHH, and Quintero et al (2021) suggested a method for co-creation of AR content using principles for universal design learning. This paper focuses specifically on AR studies for DHH people. An early study about mobile AR for DHH people was made by Parton et al (2010) using 2D barcodes and Youtube videos created by teachers themselves, to create an affordable and feasible AR-based teaching experience with early smartphones. Today, QR codes are more often used but the basic idea remains to link the physical world to virtual objects like online videos. More early studies were conducted by Zainuddin et al (2010a, 2010b) creating a dual language AR Book for teaching, where text (in Bahasa Malaysia and English) in the book was complemented by sign language videos via AR and 3D-models in AR for illustration. Al-Megren & Almutairi (2018) created a mobile AR app for learning of ArSL by mapping printed words to corresponding signs, which was shown to be more effective compared to traditional teaching approaches using ArSL, pictures and fingerspelling with 20 participants divided in two groups.

Ridha & Shehieb (2021) created a solution with real-time transcription, speech emotion recognition, sound indications features, as well as classroom assistive tools, using an affordable set of AR glasses. Falletto, Prinetto and Tiotto (2009) suggested a system for signing virtual characters. Cadeñanes Garnica & Arrieta (2014) presents a mixed reality (desktop, tablet and head mounted AR) toolset to teach fingerspelling with animated virtual characters and a physical sign-language book and provides insights into how different mixed reality modalities can be used for teaching fingerspelling. Cadeñanes & González Arrieta (2014) also developed a Sign Language Teaching Model (SLTM) called Multi-language Cycle for Sign Language Understanding (MuCy), a continuous psychomotor cycle for teaching sign language and fingerspelling using AR virtual characters with printed books.

Mirzaei, Ghorshi, & Mortazavi (2012a) presents an AR system with two modes: 1) automated speech to text and 2) facial expression to handle noisy environments where speech recognition can be hard. The text was presented on a mobile AR display to communicate with hearing people. Mirzaei, Ghorshi, & Mortazavi (2012b) added text-to-speech to the system. Dabran et al (2017) also combined AR with speech recognition to create real-time subtitles so hearing-impaired people can access live talks. In a similar vein, Ioannou & Constantinou (2018) used head mounted AR with an adolescent student with cochlear implant while communicating with teachers and tablet AR with four six-graders to learn vocabulary and improve reading skills. The communication was shown on the AR glasses screen (for the student) and on a smartphone (for the teacher). Luo et al (2022) created a synchronous sign language translation visualisation interface for head-mounted AR called Avatar Interpreter to be used in classrooms.

What emerged from this scoping review is that written texts may be implemented in an AR system for DHH people to fulfil two main functions: enhance access to contents and support spoken language learning. Since the linguistic competence in the spoken language is highly variable among the DHH population (a.o. Howerton-Fox & Falk 2019), the use of written texts may be effective to different degrees and some strategies of text adaptation may be used.

3.2 AR Game mechanics for education

There have been a significant number of studies about AR for learning. Based on a literature review by Li et al (2017) almost half of the studies found AR to be more engaging than traditional learning and more than half found AR games to be fun, interesting, or enjoyable. Based on Li et al (2017) AR game mechanics for learning are collaboration and interaction with face-to-face communication, group solving tasks, competition and sharing experiences, between students but also between students and teachers/parents. The latter had been less explored. A limitation of games was time so the activity can fit within the school schedule. Quizzes, puzzles and story-based games were most popular. Collection of items and role play were also fairly common. Quests and exploration were less common. Technically, location and image recognition were the most common inputs, whereas object recognition was used in some games. Gestures were also mentioned. (Ibid.) Face recognition was not mentioned but this may be due to issues of personal integrity for students.

3.3 Challenges for accessibility and representativeness of DHH people

The development of accessible AR games for DHH people involves several challenges related to Sign Language and DHH culture. The contribution we bring here is based on the experience obtained in two Portuguese R&D projects involving the development of video games accessible to the DHH: an online repository that integrates 26 bilingual mini-games, and GBL4deaf where the video game "Space adventure: Defend the planet!" was developed (educacaoacessivel.ulusofona.pt/en/ and gbl4deaf.ulusofona.pt/thegame/ respectively). The

following analysis is organised into five distinct dimensions: Cultural, Educational, Psychosocial, Semantic, and Multimodal.

Cultural dimension: The involvement of a DHH signer is key for the game to be welcomed by the DHH community. If we think that we are developing content in the native language of the DHH person, it becomes obvious the need to have a native person in that language for reasons of linguistic accuracy. However, at least in the case of the Portuguese reality, it is also a matter of representativeness and involvement of the DHH in the creation of a content that is intended for them. The DHH community wants to participate in the development of content that is addressed to them, in order to not only ensure linguistic accuracy but also that this same content is consistent with the vision and understanding of the world of the DHH person.

Educational dimension: In order to translate a concept correctly into a sign language, the signer must understand it in the first place. Translation from one language to another (regardless of modalities such as spoken or sign language) requires an accurate understanding of the original message. Also, the translator should be aware of the context in order to correctly express meanings from one language to the other. Thus, in the case of spoken or written content (from a non DHH author), it is crucial to involve: the hearing author of the content, the DHH signer, and the Sign Language interpreter. This will be potentially time consuming in the case of complex or abstract content, but essential for the accuracy of the message in sign language.

Psychosocial dimension: The DHH signer must trust the sign language interpreter. Although the DHH signer may have lipreading and text interpretation skills, when concepts are more complex or have been forgotten, a dialogue between the specialist or author of the topic in question will always be necessary to fully understand the message and its context. In this question-and-answer process, the DHH signer is largely dependent on the interpreter's ability to understand the content in question. If this first level of comprehension fails, the sign language message is irreparably compromised. Beyond this crucial point, the DHH must recognize the interpreter's fluency and accuracy in sign language. If this is not the case, a principle of distrust that is difficult to overcome will be established right from the start. Another important aspect is empathy between the DHH person and the interpreter which, although not essential, will certainly facilitate the process and the quality of the work.

Semantic dimension: Generally speaking, sign languages are less standardised than spoken languages. They tend to show a higher degree of linguistic variation due to various socio-linguistic factors (e.g. lack of written form, atypical language acquisition and transmission, paucity of bilingual programs, absence of TV shows in sign language). On top of that, subject-specific signs show even more variation for two reasons: i) sign languages are not typically used to teach subjects at school and ii) not many native signers have achieved a degree in some particular fields. In the specificity of the subjects, it may be hard to find the corresponding technical signs, so an alternative strategy could be fingerspelling (spelling the word with the manual alphabet). This option not only compromises the visual fluidity that underlies sign language, but also conditions the understanding of the message to the knowledge of the word in question. The message then becomes substantially more complex, making comprehension extremely difficult, which, in the case of a child, will be even more problematic given the shorter attention span that is characteristic of children. What happens in Portugal in this regard, are the schools and their teachers who create gestural codes that only work in that school. Therefore, if a DHH student changes schools, they will probably encounter signs that do not correspond to what they have learned. The recognition of the new sign as an "official sign" is the result of a slow process of dissemination by the DHH community, and there is no official entity that defines and validates these signs.

Multimodal dimension: Signing has proper grammatical rules, is typically done in combination with facial expressions and signing itself is complex. These three characteristics of sign language are very complex challenges to overcome through technology, such as "digital interpreters" in the form of virtual characters. Despite all the effort and evolution that has been made in this field, these challenges have yet to be fully resolved. What is at stake is the accuracy of the handshape, location, movement, and orientation of the hands, as well as the association of facial expressions and the fluidity of the message. As said before, a correct interpretation of sign language needs the signer to understand the context in order for the sign to be properly applied. Words (written or spoken) can have a recurring double meaning that has to be constantly checked in its context. Its passage into sign depends on this understanding, otherwise the sign will appear isolated and meaningless. In sign language, this ambiguous dimension is reinforced by the intensity of the sign and facial expressions, which can give very different meanings to the same sign. Given the challenge and the examples we

are aware of, it seems safe to say that virtual character sign language interpretation is a technology with a long way to go.

3.4 Opportunities of AR for DHH people

Automated systems like signing virtual characters and automated translation between sign language and voice has limited use due to conflicts with all five dimensions. To overcome some of the challenges with the five dimensions, civic intelligence (CI) is a promising opportunity where a community of trusted persons can provide content. One example was explored by Parton, Hancock, & Dawson (2010). Videos of trusted, DHH signers in different languages, who are knowledgeable in different subjects can potentially volunteer and upload explanations of concepts, especially those that do not have a direct language correspondence. An existing platform like Youtube or similar can make it cost effective and easy to implement (Ibid.). This CI-based video approach has potential to fit within all dimensions: the signer is DHH, knows the subject or concepts (self-reported), can handle the semantics in local languages, and include both signs and facial expressions of a real person. The potential of trust can be harder to achieve, but a ranking system (Hoisl, B., Aigner, W. & Miksch, 2007; Ling et al, 2005) may help other users to know who are the best signers for a specific subject/topic and language, and promote more volunteers. An opportunity with image recognition is to link e.g., maths formulas to a set of CI videos explaining it similar to (Parton, Hancock, & Dawson, 2010) in the local sign language (Zainuddin, Zaman, & Ahmad, 2010a) for the student. Similar solutions can also be done for other subjects, for instance with books, questions and other material within curricula could be linked to CI videos. The links can also be provided with CI either by signers but also by teachers (Parton, Hancock, & Dawson, 2010). A multimodal approach is also possible and preferred (Al-Megren & Almutairi, 2018; Cadeñanes Garnica & Arrieta, 2014) for inclusion together with non DHH people. Object recognition is another AR technology to detect three-dimensional objects in the environment either with a (depth) camera or light detection and ranging (LiDAR). Object recognition can also be combined with civic intelligence and/or machine learning to (semi)automatically tag or label objects with a description. In an educational context it may be used in more hands-on situations, for instance in a lab, a workshop or sports setting, where CI video-based instructions can be found for different tasks that the teacher wants to communicate to the students to do. Machine learning may also be used by analysing CI created signed videos and ease the dissemination of locally created signs.

3.5 Appropriateness analysis of AR interface alternatives

Table 1 shows an appropriateness analysis (Grammenos, Savidis and Stephanidis, 2007) of possible input and output design alternatives in a generic educational AR game for different player attributes.

The columns in Table 1 represent potential input/output options to the AR application. The rows represent players attributes and the then user profiles, which is a combination of the individual attributes where the lowest value is selected. The table shows that Sign recognition is Ideal (input designed especially for DHH) while Image, Object and Plane recognition are all *Appropriate* input as DHH prefers visual mediums. However, if the DHH player is a novice player, Sign recognition may raise a barrier as it can be a learning curve for specific signs (hence *Could be used*). Some outdoor locations can be dangerous for children, thus deemed *Could be used* (if there is no alternative). Scene tracking is useful for larger objects, scenes, and also indoor environments with lack of GPS signals and cloud-based anchors can be added for multiuser AR game mechanics. For output, IS *Could be used* if there is no way to have a local sign language which would be *Ideal*. Images, Animations and Video are *Appropriate*. Based on this, two user profiles can be recommended: Novice (don't rely on sign recognition), Expert (sign recognition can be used for more advanced or efficient interaction).

Table 1: Appropriateness analysis and Player profiles

Abstract task: AR game interaction in inclusive learning contexts for DHH children

	Input (to the AR game)					Output (to the player)		
	Sign Recog-nition	**Image/ Object Recog.**	**Plane Detection**	**Indoor: Scene Tracking**	**Outdoor: GPS, Scene Tracking**	**Inter-national Sign, IS**	**Local SL**	**Images, Animations and Video**
Player attributes								
DHH	Ideal	Appropriate	Appropriate	Neutral	Neutral	Could be used	Ideal	Appropriate
Novice	Could be used	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Expert	Appropriate	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Child	Neutral	Neutral	Neutral	Appropriate	Could be used	Neutral	Neutral	Appropriate
DHH Children Player Profiles								
Novice	Could be used	Appropriate	Appropriate	Appropriate	Could be used	Could be used	Ideal	Appropriate
Expert	Appropriate	Appropriate	Appropriate	Appropriate	Could be used	Could be used	Ideal	Appropriate

4. Conclusion and future work

In this study five dimensions of challenges for accessibility and representativeness of DHH people have been defined, clarifying the requirements for signed videos in apps and AR games. Civic intelligence-based videos signed by DHH have been discussed as a potential opportunity to fit all five dimensions, contrary to using virtual characters. Appropriate AR input/output options for two child AR-player profiles have been defined including sign recognition, real world images/objects/planes, animations, local signed videos as well as location-based input. Texts and International Sign can be used as a complementary modality to local sign language.

The conclusion is that the development of an inclusive, multi-language AR game for DHH people needs to be carried out as an international collaboration. Firstly, there is a need for expertise regarding each national Sign language. Another is that the development of a high-quality AR game would also need a team with skills and knowledge in areas such as AR, accessibility, game design and narration. Using a Design Science Research framework (Johannesson & Perjons, 2014), the problem of overcoming the five dimensions of including DHH people and how to do that in a mobile AR game should be explicated. Secondly, the game design requirements should be defined with a user-centred approach. Thirdly, the game should be designed in a co-creation process involving teachers and experts from organisations for DHH people. Fourthly, the game should be distributed and tested in schools by DHH learners. A core design approach is user centred design. A challenge is to include DHH children in the co-design process, in accordance with “nothing about us without us”. This includes ethical considerations, especially to involve DHH children. Another challenge is how to create inclusive solutions and game mechanics that are appreciated by both DHH and non-DHH people. The design ideas presented in this study can be the basis for the design and development of an AR-game for DHH children in an educational context.

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