Metaverse4Deaf: Assistive Technology for Inclusion of People with Hearing Impairment in Distance Education Through a Metaverse-Based Environment

Adson Damasceno[1][a], Lidiane Silva[2], Eudenia Barros[2] and Francisco Oliveira[2]

[1] *State University of Ceara (UECE), Mombaça Campus, Mombaça CE, Brazil*

[2] *UECE, State University of Ceara, Fortaleza, Brazil*

Keywords: Human-Computer Interaction, Assistive Technology, People with Disabilities, Distance Education, Metaverse.

Abstract: In the context of the COVID-19 pandemic, emphasizing the importance of digital transformation in education, this work in progress (Position Paper) addresses the imperative of inclusion and accessibility, particularly for individuals with disabilities. While the Dell Accessible Learning (DAL) platform has benefited 60,000+ users in remote learning, incorporating disruptive technologies like Metaverse could improve hands-on learning for people with disabilities. Metaverse augmented and virtual reality offers unique opportunities, but challenges remain in ensuring accessibility features. Focused on enhancing the DAL for deaf people, the research involves prototyping Metaverse solutions, considering impacts on users with and without disabilities. Challenges include optimizing the user experience and representing behaviors such as gestures and facial expressions.As an innovation proposal, this ongoing research involved collecting user data to elicit requirements, prototyping, and developing the minimum viable product of the metaverse environment, in addition to usability and acceptance tests with groups of users with disabilities. Central to the Metaverse is the representation of human behaviors, necessitating the understanding and translation of gestures from individuals with disabilities. The investigation culminates in a proposal validation experiment, a fundamental step towards achieving truly inclusive and accessible education through the Metaverse.

1 INTRODUCTION

Metaverse plays a vital role in education. As indicated by scholars, there are several potential applications of the Metaverse in education, such as medical, nursing, and healthcare education, science education, military training, and manufacturing training as well as language learning (Jovanović and Milosavljević, 2022). The concept of Metaverse first occurred in 1992 and drew attention with its movie Ready Player One (Cline, 2011). Metaverses are immersive three-dimensional virtual worlds (VWs) in which people interact as avatars with each other and with software agents, using the metaphor of the real world but without its physical limitations. This broad concept of a metaverse builds on and generalizes from existing definitions of VW metaverses, providing virtual team members with new ways of managing and overcoming geographic and other barriers to collaboration. These environments have the potential for rich and engaging collaboration, but their capabilities have yet to be examined in depth (Davis et al., 2009). Metaverses offer immersive virtual realities with potential applications in distance education. Integrating Metaverse with assistive technology enables educational advancements and inclusive participation (Damasceno et al., 2023). The original goal of using Metaverse in education is encouraging more people to engage in them. As a result, it is necessary to create an inclusive virtual environment that considers as many different participant requirements as possible. For example, affordability is inevitably an issue for poor groups, but they urgently consider education a life-changing opportunity. Respecting the needs of special learners, such as people with disabilities or religious, is often more important than providing a high-quality education (Tlili et al., 2022).

There is a need to research the literature on the state of the art of Assistive Technology (AT) for Distance Education (DE) Research in a Metaverse-Based Environment to explore the interaction between the Metaverse, AT, and DE. We searched previous liter-

[a] https://orcid.org/0000-0001-6570-4103

Damasceno, A., Silva, L., Barros, E. and Oliveira, F.
Metaverse4Deaf: Assistive Technology for Inclusion of People with Hearing Impairment in Distance Education Through a Metaverse-Based Environment.
DOI: 10.5220/0012700200003693

In *Proceedings of the 16th International Conference on Computer Supported Education (CSEDU 2024) - Volume 1*, pages 510-517
ISBN: 978-989-758-697-2; ISSN: 2184-5026

ature to gather, organize, and analyze evidence. Although we found a limited number of studies explicitly addressing accessibility in the Metaverse, these articles emphasized the need for solutions to ensure that People with Disabilities (PwD) can fully access and participate in these virtual environments. Challenges associated with implementing accessibility in the Metaverse include adapting interfaces for different disabilities, the availability of compatible AT, and raising awareness among developers about the specific needs of PwD. These findings encouraged us to research and develop inclusive and accessible educational solutions in the Metaverse, promoting equal opportunities and rights for all.

Our Problem Statement is that PwD students do not feel comfortable in collaborative environments because of their disability. So, a metaverse-based platform where disability limitations are not revealed can provide a more welcoming and inclusive environment for PwD by facilitating collaboration, given that collaboration is essential for learning to integrate into communities. This position paper proposes an integrative framework for including people with hearing impairment in DE through a metaverse-based environment. The research findings from the present study help develop a better understanding of how to evolve in research and develop innovative solutions through the Metaverse that enable grounding constraints for PwD, especially in this study, people who are deaf or hard of hearing.

The remainder of this paper is organized as follows. Section 2 gives an overview of the Education, Metaverse, and Assistive Technologies. In Section 3, we discuss our methodology. Section 4 describes the proposed framework and discusses Human-Computer Interaction (HCI) theories in our approach. Furthermore, it presents a real case in practice, and Section 5 mentions the conclusions we can draw from our work.

2 BACKGROUND

Metaverse in Education. Lin et al. (2022) explore integrating traditional education with Web 2.0 through MOOCs, highlighting certain limitations, such as the lack of engaging content and low student participation. Recognizing the imminent arrival of Generation Z, who are familiar with online education, preparing for a new revolution in educational models becomes crucial. Leveraging the potential of the Metaverse can be particularly beneficial since it offers interaction, authenticity, and immersive experiences. According to Fernandes and Werner (2022), the Metaverse is a new paradigm under construction where social, immersive virtual reality platforms will be compatible with several kinds of applications.

In this context, applications of this metaverse must serve as relevant tools for PwD. Ball (2022) emphasized the importance of ensuring the metaverse is accessible to individuals with disabilities, recognizing them as valuable contributors. However, he did not specify any particular disability or explain how accessibility and inclusion should be effectively achieved. In this direction, there is a conceptual highlight of AT as an association between products and services, considering that these are associated with both the need for information accessibility and physical accessibility (Vianna and Pinto, 2017).

Assistive Technology. Assistive technologies play a vital role in the daily practice of Virtual Learning Environments (VLE), triggering significant educational transformations. The integration of information technology in education has been crucial to enhancing students' access and participation, regardless of their abilities or limitations. AT is a term used to identify the arsenal of resources and services that contribute to providing or expanding the functional abilities of PwD and, consequently, promoting their independent life and inclusion (Bersch, 2008).

3 RESEARCH METHOD

Literature Survey. We carried out a bibliographic survey to gather, organize, and analyze the evidence available in the literature and research trends on the metaverse, AT, and DE (Damasceno et al., 2023). To achieve the proposed objective, we carry out a Rapid Review (RR) (Cartaxo et al., 2018), as it has essential characteristics that: 1) reduce the costs of complicated methods, 2) provide specific evidence, 3) operate in close collaboration with professionals and relate results by convincing means. The aspects considered are relevant to our context, as some authors are professionals from a company that specializes in creating innovative and accessible solutions for different groups, including DE and TA, seeking to obtain initial insights into integrating the metaverse alongside these two concepts.

Answering the Following Questions. RQ1) How has the publication of primary studies evolved over the years? RQ2) What domains are being explored in studies addressing accessibility in DE within the metaverse context, and how are they approaching it? RQ3) What challenges are associated with implementing accessibility in educational metaverse platforms? RQ4) What research and empirical strategies and methodological approach are being used?

Our RR findings indicate that most proposals were published in Journals (57%) between the years 2020 and 2023. The Chemistry Lab context was the main focus of most studies, comprising three studies (42.5%). Most returned studies employed evaluation research (57.1%) as their strategy. Empirical experiments were conducted in 42.8% of the studies, and the quality-quantitative method was applied in 71.4%. Regarding the challenges of implementing accessibility in the metaverse, we highlighted the instrumentation, technical problems, complex systems, student performance, sense of presence, and accessibility assessment. Finally, we generated an Evidence Briefing [1] based on our findings to make the RR more appealing to practitioners.

Related Works. The studies explored metaverse and education (Alfaisal et al., 2022) (Onggirawan et al., 2023), and metaverse and accessibility (Fernandes and Werner, 2022). Unlike these studies, our review considered the three pillars together to understand how accessibility is being considered in metaverse-based distance learning environments. In addition, we identify open challenges to meet practitioners' perceptions in a real-world environment and support researchers by pointing out study possibilities to assist PwD. This study proposes an innovative approach to promote inclusive and accessible education through an integrative framework to include people with hearing impairments in distance education through a metaverse-based environment, Figure 1.

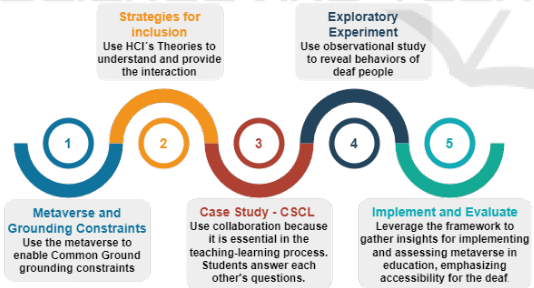

Figure 1: Infographic for framework vision with processes.

4 FRAMEWORK M4DEAFVERSE

4.1 Metaverse and Grounding Constraints

According to Kendon (2004), willing or not, humans, when in co-presence, continuously inform one another about their intentions, interests, feelings, and ideas using visible bodily action. For example, it is through the orientation of the body and, mainly, through the orientation of the eyes that information is provided about the direction and nature of a person´s attention. Considering the presence of avatars in the metaverse, access to the avatar's embodied behavior will undoubtedly provide more opportunities for understanding for a deaf student, and this behavior is not restricted to signing in sign language.

Considering grounding constraints, metaverse technology can enable Clark's common ground constraints. That is, it can provide a common basis of understanding and reference among participants in an interaction. The metaverse is a virtual representation of the real world or a shared virtual space where people can interact, collaborate, and participate in different activities. In the context of the metaverse, "grounding constraints" can be the elements or characteristics that ensure participants have a shared understanding of the virtual environment. This includes representing objects, actions, and interactions in a consistent and understandable way. Clark's "common ground" theory refers to the knowledge shared between interlocutors in a conversation. The baseline allows for effective communication, as both sides have a mutual understanding of what is being discussed. In the context of the metaverse, "grounding constraints" can be the design elements, conventions, and norms that guarantee the creation of this "common ground." This may include the consistent representation of objects, gestures, facial expressions, and other forms of nonverbal communication in the virtual environment.

Metaverse technology can enable common ground constraints, as proposed by Herbert Clark. Such constraints can refer to the information, perspectives, and understandings shared between people in a communicative interaction (Clark, 1992). Metaverse is an enormous framework that owns many digital features of the future. There are numerous benefits in the Metaverse world, like interaction, authenticity, and portability. As a result, the new educational system has to be readdressed to retain its accessibility and prolong its existence (Lin et al., 2022).

The metaverse enables grounding constraints. According to Lin et al. (2022), there are changes that the metaverse can bring to education. Among these changes, we highlight in this study the one related to connection, that is, it could be the issue of connecting remotely; it is a quick connection, and it will offer you communication and interaction with other people at any time and anywhere. So, one of the positive consequences is to make it possible to "see what I see."

The avatar can see the other avatars cohabiting in the same virtual world. "Grounding Constraints" re-

[1] https://zenodo.org/records/8286438

fer to the synchronization of perceptions between participants, such as what they see, hear, or feel. In the context of the metaverse, this synchronization is enhanced as users simultaneously share the same virtual space, which significantly improves communication for people with hearing impairments. That is, it relates to what, for example, "what I see," "what you see," "if we are seeing the same thing," "if we are hearing the same thing," "if we are feeling feeling the same temperature," are things that facilitate communication, so that is why the metaverse will be better able to improve these "Grounding Constraints" because the subject will see things that other subjects will see at the same time, in short, the sense of presence it must, be that thing that we call immediate physical co-presence, that is when people are in the same place, they see the same things, feel the same things, see each other's bodies, see each other's behavior incorporated from the other and this greatly facilitates communications.

That said, imagine the scenario where the teacher teaches a little class and divides the students into groups to carry out an activity. Metaverse technology can play a significant role in improving such constraints. Among the possibilities, we highlight **a) Virtual Presence.** In the metaverse, participants can create avatars representing their virtual presence. This allows for a richer form of communication, as gestures, facial expressions, and even movements can be represented. This makes understanding colleagues' intentions and emotions easier, reinforcing common ground, **b) Content Sharing.** Metaverse platforms often offer tools for real-time content sharing. During the discussion, students can share presentations, documents, and other relevant information. This instant and synchronized sharing helps keep everyone in the same context of information, promoting common ground, **c) Collaborative Environment.** Metaverse environments can provide collaborative virtual spaces where groups can discuss the designated activity. These environments can simulate classrooms or meeting rooms, creating a sense of co-presence, similar to being physically at a table. This helps in building a shared common ground, **d) Multimodal Interaction.** With metaverse technology, communication is not limited to text alone. Audio, video, and other multimodal interaction modes are available. This variety of modes of communication allows for a richer expression of ideas, facilitating mutual understanding and thus contributing to the development of a robust common ground, **e) Immediate Feedback.** Metaverse tools often allow for immediate feedback. During the group activity discussion, participants can provide instant feedback, clarify doubts, and correct misunderstandings. This helps with continually adapting the common ground as the conversation progresses, **f) Accessibility and Inclusion.** The metaverse can be a more inclusive solution, allowing the participation of students who, due to geographic or physical limitations, cannot be physically present. This contributes to a more diverse common ground.

4.2 Strategies for Inclusion

In HCI, it is imperative to recognize that many of the methods, models, and techniques used in this field are based on different psychological theories, mainly cognitive, ethnographic, and semiotic. Card et al. (1983) proposed a psychology applied to information processing among these theoretical approaches in HCI. According to them, HCI involves the user and the computer engaging in a communicative dialogue to perform tasks. This dialogue's mechanisms constitute the interface: the physical devices, such as keyboards and screens, and the computer programs that control the interaction. Its objective was to create psychology based on task analysis, calculations, and approximations so that the system designer could achieve a balance between computational parameters of human performance and engineering variables.

According to Card et al. (1983), task structure analysis provides predictive content of psychology. Once we know people's goals and consider their perception and information processing limitations, we should be able to answer questions such as: How long does it take a person to perform the predefined physical tasks that allow them to achieve their goals?

4.2.1 Human Information Processing: Human Perception

Based on information processing psychology, Card et al. (1983) proposed the Model Human Processor (MHP). According to them, using models that see the human being as an information processor provides a common framework for integrating models of memory, resolution problems, perception, and behavior. Considering the human mind as an information processing system, it is possible to make approximate predictions of part of human behavior.

According to Barbosa et al. (2021), the MHP comprises three subsystems, each with its memories and processors, along with some operating principles: the perceptual, the motor, and the cognitive, Figure 2.

Figure 2 presents a generic representation of an information processing system. At the center is a processing executive that operates in a recognition-action cycle. In each cycle, the information available by the receivers and coming from the internal

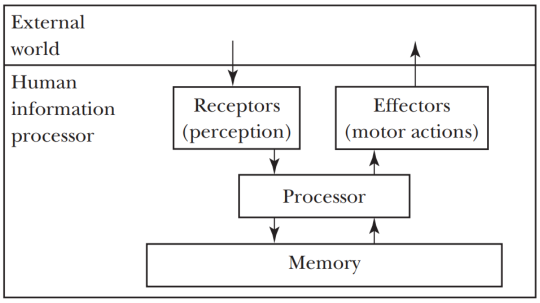

Figure 2: A generic human information processing system (Carroll, 2003).

memory is compared with a set of patterns, generally expressed as a set of if-then rules called productions. This confrontation triggers actions (or operators) that can change the state of internal memory and modify the external world through effectors. The cycle then repeats itself. For ease of use, some information processing models do not detail this complete structure, but it is implicit in their assumptions.

Treating the human as an information processor, albeit a simple stimulus-response controller, allowed the application of information theory and manual control theory to problems of display design, visual scanning, workload, aircraft instrument location, flight controls, air-traffic control, and industrial inspection, among others. Fitts' Law, which predicts the time for hand movements to a target, is an example of an information processing theory of this era (Carroll, 2003).

According to Carroll (2003), the natural form of information processing theories is a computer program, where a set of mechanisms is described locally, and where larger scale behavior is emergent from their interaction. The claim is not that all human behavior can be modeled in this manner, but that, for tasks within their reach. Newell et al. (1972) adds that, it becomes meaningful to try to represent in some detail a particular man at work on a particular task. Such a representation is no metaphor, but a precise symbolic model on the basis of which pertinent specific aspects of a man's problem solving behavior can be calculated.

The perceptual system transmits sensations from the physical world detected by the body's sensory systems (vision, hearing, touch, smell, taste) to internal mental representations. Central vision, peripheral vision, eye movements, and head movements operate as an integrated system, providing us with a continuous representation of the visual scene of interest. These sensations are temporarily stored in areas of sensory memory (mainly visual and auditory memories), still physically encoded and with a rapid forgetting time, depending on the intensity of the stimulus. Then, some of these sensations are symbolically encoded and stored in working memory (Barbosa et al., 2021).

The metaverse, a three-dimensional virtual space, offers revolutionary opportunities for inclusive education, especially for people with hearing impairments. The integration of HCI Theory, focusing on "embodied behavior," becomes crucial to understanding how avatar gestural interactions can enhance inclusion and autonomy in this context. HCI theory highlights "embodied behavior," which recognizes the importance of interaction between the user and the interface, considering gestures, movements, and expressions. In the educational metaverse, this translates into avatars capable of reproducing the user's gestures naturally and intuitively, enriching communication.

Given this scenario, it is viable to design strategies aimed at inclusion, with particular emphasis on expanding the autonomy of PwD, notably those with hearing impairment. As an example, the following approaches stand out: **Strategies to Expand Inclusion.** (I)Virtual Sign Language: Avatars can be programmed to interpret sign language, allowing users with hearing impairments to communicate through virtual gestures and emulations of sign language. (II)Accessible Virtual Spaces: Virtual environments can be adapted to accommodate different learning styles, incorporating visual and interactive resources that facilitate understanding concepts. **Strategies to Increase Autonomy.** (I)Exemption from Interpreters: The avatar's ability to interpret and reproduce gestures minimizes the dependence on interpreters in educational contexts, granting greater autonomy to students with hearing impairments. (II)Experience Personalization: Avatars can be customized to fit individual preferences, providing a more personalized and independent learning experience.

These strategies represent an innovative approach, providing increased inclusion and autonomy through gestural interactions of avatars. These technologies hold the potential to substantially reconfigure the educational experience, creating a more accessible, personalized, and independent environment for people with hearing impairments.

This approach allows for a variety of interactions, exemplified by: (I) Virtual Classes: Avatars can reproduce the teacher's gestures, making classes more engaging and understandable for students with hearing impairments; (II) Collaboration on Projects: Collaborative work environments enable avatars to communicate ideas through gestures, encouraging active participation in educational projects e (III) Practical Simulations: Virtual environments can simulate real-world situations, where avatars interact through gestures to solve problems, providing practical and autonomous learning. This study focuses on the second example mentioned, “project collaboration.”

4.2.2 Discussion

Affordances, represented by drawings, play a crucial role, conveying possibilities for interaction. Superimposing real-world interaction history onto metaverse elements, such as tables and boards, enhances user engagement. While these objects may possess magical capabilities, preserving their inherent functions ensures a seamless transition for users. This approach aligns with Embodied Interaction theory, aiming to incorporate real-world behaviors into metaverse avatars, providing an expressive outlet, especially for users with disabilities like deafness.

The Figure 3 illustrates a tablet where the user’s perspective shifts as they move, emphasizing the importance of leveraging affordances for interaction. For instance, the interaction control on the tablet dynamically responds to the user’s focused object, presenting relevant commands. The proposed research explores integrating such affordances into the metaverse, enhancing interaction for users with hearing impairments. In this metaverse environment, objects exhibit a history of real-world interactions, offering users a familiar and intuitive experience.

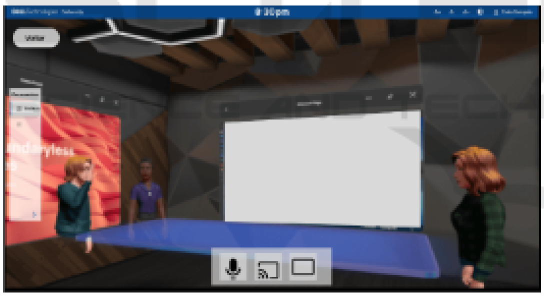

Figure 3: Embodied Behavior.

The proposed solution involves collecting embodied behaviors and embedding them into avatars, serving as alternative to sign language. This approach mitigates the limitations associated with sign language, making interaction more inclusive and cost-effective. The metaverse environment can be configured akin to real-world scenarios, facilitating the transfer of experiences and behaviors. By reducing gaps and aligning with HCI theories, this approach allows for a smoother transition of natural behaviors to the virtual realm. The study considers the challenge of mapping natural gestures to a virtual environment, emphasizing the need to comprehend and adapt behaviors for users, particularly those with hearing impairments. The solution involves understanding and configuring virtual environments, such as classrooms or collaborative spaces, to accommodate these behaviors.

Communicational affordances govern how people collaborate; that is, the medium in question determines how the person expresses themselves. Different media enable different forms of manifestation. The importance of obtaining grounding constraints stands out here, where ”grounding” refers to the ground, representing fundamental and immutable truths that serve as the basis for behaviors and interactions. Sensory aspects such as vision, hearing, and smell are grounding constraints that provide a solid basis for understanding the environment.This principle is intrinsic to human nature and is shared with animals, as evidenced by the collaboration between humans and dogs in joint activities. Collaboration between species is considered more primitive, based on the essential elements of life and survival.

The theory of grounding constraints highlights the need for a solid and reliable basis for human interactions, with the importance of understanding embodied behaviors. When transferring these principles to the metaverse, it is crucial to consider how the translation of natural behaviors to virtual environments can impact the strength of these grounding constraints. It is worth highlighting the relevance of body language as a primitive form of communication, closer to the truth and less subject to linguistic manipulations. The transition to virtual environments introduces a layer of cognitive processing, which can influence the strength of natural grounding constraints. Furthermore, the peculiarity of deaf communication must be considered, as they use three-dimensional (3D) space during conversations. Spatiotemporal language plays a significant role, where specific gestures and hand configurations have distinct meanings depending on spatial location and orientation, revealing the complexity of gestural communication in virtual environments.

4.3 Case of Study (CSCL)

4.3.1 DALverse

DALverse is one of several products developed in a development and innovation laboratory (Nascimento et al., 2017), as well as several other products, for example, STUART (Damasceno et al., 2020) and JLOAD (Silva et al., 2014). It integrates with DAL, a distance learning platform with several professional courses and tools that facilitate student learning and make teaching accessible for people with physical, hearing, and low vision disabilities, among others (de MB Oliveira et al., 2016). Upon joining the DAL, students enrolled in a course are granted access to the “Metaverse” room. In this context, the user can personalize their representation in the environment, choosing between three types of pre-defined avatars: male profile, female profile, or profile with no defined gender, the latter represented by a robot avatar.

Within this environment, the user has the possibility of moving around. Locomotion is controlled using the arrow keys on the keyboard and mouse, Figure 4.

Figure 4: DAL's Metaverse Environment with Avatars.

Each avatar, except the robot, has five movements: forward, backward, right, left, and resting. The robot avatar, in turn, moves by floating in these exact directions. The system interprets and reproduces each of these movements, providing the sensation of movement within the virtual environment.

4.3.2 Promoting Inclusion in Education

Promoting inclusive education offers significant benefits, such as developing social skills, encouraging empathy, building more enriching educational environments, contributing to developing collaborative skills, and promoting understanding. Quek and Oliveira (2013) present the advantages of promoting inclusive education. Simulating a classroom environment that promotes collaboration, a blackboard was developed with the resources of an eraser, pencil, and text insertion with variations in color and size. One user at a time can use the tool. Others can request to edit the board using their virtual "tablet". In this way, we guarantee greater control of resources and security in the learning environment, Figure 5.

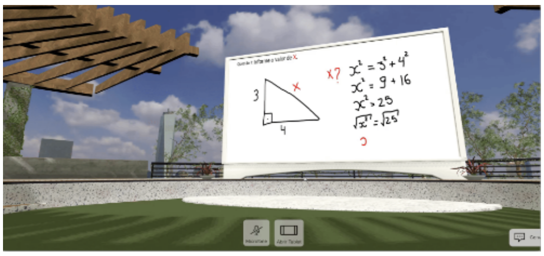

Figure 5: Collaborative Activity on the Virtual Whiteboard.

Once the owner of the whiteboard, the user will be able to transmit a browser guide, application window, or an entire screen of the device, with or without including audio on the digital whiteboard. This allows tutors and students to present their work, questions, and other external applications on their computers.

4.3.3 The Scenario

The scenario will be that of a university debate room, with a table arranged in a circular format to promote interaction between participants. There will be objects on the table, such as laptops, documents, pens, and support materials, simulating a typical teamwork environment. In addition, a multimedia presentation that the working group developed will be held using visual and auditory resources.

4.4 Exploratory Experiment

In this context, it is relevant to explore how communication can be facilitated in the Metaverse, especially in educational scenarios, where collaboration is essential. One question can be raised is how a deaf person could interact naturally in the Metaverse, participating in collaborative activities without depending on an interpreter. Identifying and listing the main incorporated behaviors capable of supporting communication and collaboration are challenges to be faced.

In order to overcome this challenge, it is suggested to carry out an observational experiment where deaf and hearing people physically collaborate in an activity after attending a virtual class. After consuming the virtual class, the proposed experiment would observe how these groups interact in the same physical space. The goal would be to gain insights into implementing these dynamics in the Metaverse.

The exploratory experiment would include an in-depth analysis of the observed behaviors, aiming to identify those essential to establishing grounding constraints and facilitating collaboration in the Metaverse. Understanding these behaviors would be crucial for effectively transitioning interactions from natural to virtual environments.

We intend to rely on linguistics experts, highlighting the importance of an interdisciplinary approach and recognizing the need to integrate specific knowledge to effectively address the translation of behaviors and interactions into the Metaverse. Filming fundamental interactions between deaf and hearing people aims to create a practical database to understand the nature of behaviors and facilitate the transition of these interactions to the virtual environment, emphasizing the relevance of grounding constraints for deaf people in the context of the Metaverse.

5 CONCLUSIONS

Metaverse4Deaf proposes an integrative structure to incorporate individuals with hearing impairment in the context of distance education, using an environment based on metaverse. The main objective is to understand the behavior of deaf people through exploratory study. This approach aims to identify emerging behaviors in interaction, outlining elements that can be integrated into the metaverse environment. Implementing these behaviors in this environment would result in an improved version whose requirements were extracted from an ethnographic study as a requirements elicitation technique.

Future developments include implementing the results into DALverse, derived from the continued application of the developing framework. This implementation process seeks to evaluate both Metaverse4Deaf and the interaction of deaf individuals in a collaborative distance learning environment based on the metaverse. It should be noted that this framework is constantly being improved, characterizing itself as a work in progress.

REFERENCES

Alfaisal, R., Hashim, H., and Azizan, U. H. (2022). Metaverse system adoption in education: a systematic literature review. *Journal of Computers in Education*, pages 1–45.

Ball, M. (2022). The metaverse: what it is, where to find it, and who will build it. 2020.

Barbosa, S. D. J., Silva, B. S. d., Silveira, M. S., Gasparini, I., Darin, T., and Barbosa, G. D. J. (2021). *Intera¸cão Humano-Computador e Experiência do Usuario*. Autopublica¸cão.

Bersch, R. (2008). Introdução à tecnologia assistiva. *Porto Alegre: CEDI*, 21.

Card, S. K. (2018). *The psychology of human-computer interaction*. Crc Press.

Carroll, J. M. (2003). *HCI models, theories, and frameworks: Toward a multidisciplinary science*. Elsevier.

Cartaxo, B., Pinto, G., and Soares, S. (2018). The role of rapid reviews in supporting decision-making in software engineering practice. In *Proceedings of the 22nd International Conference on Evaluation and Assessment in Software Engineering 2018*, pages 24–34.

Clark, H. H. (1992). *Arenas of language use*. University of Chicago Press.

Cline, E. (2011). *Ready player one*. Ballantine Books.

Damasceno, A., Soares, P., Santos, I., Souza, J., and Oliveira, F. (2023). Assistive technology for distance education in metaverse-based environment: A rapid review. *Anais do XXXIV Simpósio Brasileiro de Informática na Educação*, pages 693–706.

Damasceno, A. R., Martins, A. R., Chagas, M. L., Barros, E. M., Maia, P. H. M., and Oliveira, F. C. (2020). Stuart: an intelligent tutoring system for increasing scalability of distance education courses. In *Proceedings of the 19th Brazilian Symposium on Human Factors in Computing Systems*, pages 1–10.

Davis, A., Murphy, J., Owens, D., Khazanchi, D., and Zigurs, I. (2009). Avatars, people, and virtual worlds: Foundations for research in metaverses. *Journal of the Association for Information Systems*, 10(2):1.

de MB Oliveira, F. C., de Freitas, A. T., de Araujo, T. A., Silva, L. C., Queiroz, B. d. S., and Soares, É. F. (2016). It education strategies for the deaf-assuring employability. In *International Conference on Enterprise Information Systems*, volume 3, pages 473–482. SCITEPRESS.

Fernandes, F. and Werner, C. (2022). Accessibility in the metaverse: Are we prepared? In *Anais do XIII Workshop sobre Aspectos da Interação Humano-Computador para a Web Social*, pages 9–15. SBC.

Jovanović, A. and Milosavljević, A. (2022). Vortex metaverse platform for gamified collaborative learning. *Electronics*, 11(3):317.

Kendon, A. (2004). *Gesture: Visible action as utterance*. Cambridge University Press.

Lin, H., Wan, S., Gan, W., Chen, J., and Chao, H.-C. (2022). Metaverse in education: Vision, opportunities, and challenges. *arXiv preprint arXiv:2211.14951*.

Nascimento, M. D., Queiroz, B., Guimaraes, M., Silva, L. C., Soares, E., Oliveira, F., Ribeiro, D., and Ferreira, C. (2017). Aprendizado acessivel. In *Anais dos Workshops do Congresso Brasileiro de Informática na Educaçao*, volume 6, page 110.

Newell, A., Simon, H. A., et al. (1972). *Human problem solving*, volume 104. Prentice-hall Englewood Cliffs, NJ.

Onggirawan, C. A., Kho, J. M., Kartiwa, A. P., Gunawan, A. A., et al. (2023). Systematic literature review: The adaptation of distance learning process during the covid-19 pandemic using virtual educational spaces in metaverse. *Procedia Computer Science*, 216:274–283.

Quek, F. and Oliveira, F. (2013). Enabling the blind to see gestures. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 20(1):1–32.

Silva, L. C., de MB Oliveira, F. C., De Oliveira, A. C., and De Freitas, A. T. (2014). Introducing the jload: A java learning object to assist the deaf. In *2014 IEEE 14th International Conference on Advanced Learning Technologies*, pages 579–583. IEEE.

Tlili, A., Huang, R., Shehata, B., Liu, D., Zhao, J., Metwally, A. H. S., Wang, H., Denden, M., Bozkurt, A., Lee, L.-H., et al. (2022). Is metaverse in education a blessing or a curse: a combined content and bibliometric analysis. *Smart Learning Environments*, 9(1):1–31.

Vianna, W. B. and Pinto, A. L. (2017). Deficiência, acessibilidade e tecnologia assistiva em bibliotecas: aspectos bibliométricos relevantes. *Perspectivas em Ciência da Informação*, 22:125–151.