Introducing VISTA-SL: A Multilingual e-Learning Platform for Deaf and Hearing Learners of Sign Languages

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Abstract

This article introduces the VISTA-SL project, which aims to create an integrated e-learning platform for four European sign languages: German Sign Language, Greek Sign Language, Irish Sign Language, and Dutch Sign Language. Designed as a complement to face-to-face classes, the VISTA-SL platform will combine expertise in sign language education and education technologies to provide an adaptive and interactive learning environment suitable for deaf, hard of hearing and hearing users seeking to learn a sign language, whether it constitutes their first language or not. Building on a co-ordinated curriculum that covers vocabulary, grammar and Deaf culture materials, the platform will provide video material presented by deaf L1 signers, together with games and gamification features to motivate learning, while also providing several assistive technologies. By leveraging cutting edge language processing and computer vision approaches, the platform will provide augmented reality feedback, 3D avatars and an LLM-based virtual instructor, as part of the learning environment. VISTA-SL is developed in collaboration with end-user focus groups, comprising deaf, hard of hearing and hearing individuals. This will serve to ensure that the educational platform aligns with the expectations and needs of its intended users.

Keywords: sign language education, language learning, education technologies, deaf mobility

1. Introduction

Learning a signed language (SL) is a complex task. In addition to developing proficiency in a sign language, it is critical that learners also understand the cultural aspects and significance of learning a minority language. Learner needs also differ depending on whether their first language is a spoken language or another sign language.

According to the World Health Organisation, up to 5 out of every 1,000 children are born with hearing loss or acquire it soon after birth, yet the infrastructure for sign language education remains inadequate (Altun, 2025). While traditional face-to-face SL education is considered the 'gold standard' for both teaching and learning SLs (providing immediate feedback, visual interaction and cultural immersion), Europe is faced with a significant and ongoing shortage of qualified SL instructors and supporting learning materials (Mathews, 2020). This presents a critical challenge for the region. This issue is further highlighted as SLs gain legal recognition as full natural languages that are independent from spoken languages and as the primary languages of deaf[1] communities.

Advances in digital technologies provide the potential to support both SL instructors and SL learners with regard to teaching and learning support tools – regardless of the hearing status. These advances leverage technological approaches to provide learners with unique advantages, including visual sign demonstrations from various perspectives, and responsive and sometimes immediate feedback mechanisms. Advances in neural

[1]Based on the critical discourse of whether to differentiate audiological status and cultural identity through different capitalisations of *deaf*, we follow Kusters et al. (2017) and others in using lowercase *deaf* throughout to avoid an unintentional dichotomy or possible exclusion of individuals that do not neatly fit in these categories.

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natural language processing and computer vision have been harnessed to develop digital tools that empower learners, allowing them to adopt a suitable pace based on personal preference and ability, while also supporting access to education from remote locations and flexible on-demand delivery.

This paper presents VISTA-SL[2] (Visual Interactive System for Teaching and Assessment of Sign Languages), an integrated e-learning platform that provides the potential to support SL teaching and learning through the use of a novel combination of augmented reality visual feedback, 3D avatar technology, and Large Language Model (LLM) powered personalised feedback. The platform will provide curricula for multiple sign languages, covering vocabulary, grammar, interaction, and Deaf culture, as well as games for language learning. Both deaf and hearing learners are taken into account in the design of the curricula and platform interface.

The remainder of the paper is structured as follows. In section 2, we provide an overview of VISTA-SL as a tool for teaching and learning. Section 3 outlines previous and current research in the area, representing both technical and educational aspects. A description of the curriculum development is provided in section 4, followed by the employed education technologies in section 5. In section 6, we discuss the VISTA-SL platform with regard to its architecture, user progress tracking, accessibility and privacy. We conclude the paper in section 7 and outline the future direction of our work.

2. VISTA-SL for Teaching and Learning

VISTA-SL is an Erasmus+ project involving six partner institutions across five European countries. It aims to provide accessible, open sign language education that can scale beyond the limitations of traditional classroom instruction. The platform provides support four European sign languages:

- German Sign Language (DGS)
- Greek Sign Language (GSL)
- Irish Sign Language (ISL)
- Dutch Sign Language (NGT)

Entries are cross-linked between languages, allowing interested users to compare different languages. VISTA-SL is designed for two groups of second language learners (L2) that differ in their familiarity with the visual language modality: Signers learning another sign language (L2M1) and learners that encounter SLs for the first time (L2M2).

The coordinated curriculum, together with the technical components of this project, are steered and evaluated by focus groups. The focus groups include deaf and hearing students as well as established deaf sign language teachers. By including deaf course instructors, VISTA-SL supports the position that deaf people must be at the forefront of teaching their own first language. Learners are provided with the benefit of learning sign language from deaf L1 signers, while also experiencing insight into deaf culture. This approach is instrumental in preserving authenticity, while also promoting role models.

VISTA-SL is informed by the Common European Framework of Reference for Languages (CEFR)[3] (Council of Europe, 2020) and the ProSign project[4] regarding descriptors for reception, interaction and production, although it follows a different level structure that more directly integrates with the platform's goals. VISTA-SL also builds on experiences made creating an e-learning platform prototype in the CAT-SL project (Blekos et al., 2026)[5].

The VISTA-SL project has the following key objectives and contributions:

- Creation of interactive learning curricula and educational games in four EU sign languages, designed for deaf and hearing users and developed by sign language educators and linguists.
- Design of a modular, accessible web platform with privacy-preserving architecture.
- Development of real-time AR feedback tools using hand and facial landmark detection to provide immediate visual guidance on sign execution accuracy.
- Integration of 3D signing avatars for demonstrating correct sign production, with controllable playback for detailed examination.
- Implementation of an LLM-based virtual instructor that provides personalised coaching based on learner progress and performance patterns.

2.1. Representation

Sign languages are intrinsically linked with the deaf communities from which they originate. When developing educational materials and technologies centred around these languages, it is essential to involve these communities in meaningful ways

[2] https://vista-sl.eu/

[3] www.coe.int/lang-cefr

[4] https://www.ecml.at/en/ECML-Programme/Programme-2012-2015/ProSign

[5] http://cat-sl.eu

throughout the entire life cycle of a project (Harris et al., 2009; Desai et al., 2024).

In this project, deaf signing people are involved on all levels: as principal investigators, as scientific researchers, as teachers, as students, as learners, and as focus group members. Thereby, deaf-led and participatory research—which is ranked very highly in current discussions about the primacy of deaf people in the research and development of technology for deaf people—plus taking an applied perspective into account at all steps of the project, is given space as much as possible. Above all, including deaf and hearing learners and deaf educators as target groups is essential, thus considering their respective needs and requirements as platform users. Feedback from these groups has a direct impact on both the educational content, technology implementation and platform interface.

3. Related Work

3.1. Sign Language Education

For second language learners, it matters whether their first language is in the same modality (M1) or another (M2). Signers learning another sign language (L2M1) and learners that encounter SLs for the first time (L2M2) therefore represent two distinct groups of learners (Schönström and Holmström, 2022). Testing previous assumptions on second language learning, several studies on L2M1 and L2M2 learners find important differences in challenges and opportunities for these groups (cf. Chen Pichler and Koulidobrova, 2015).

For us, it is important to offer both groups learning opportunities on a par. SL teachers encounter various topics that L2 learners struggle with (Woll, 2012) and deaf didactics has not yet been sufficiently studied (Ladd, 2022; Grote et al., 2018; Karar et al., 2017; Metzger, 2008). Practising outside the classroom in a guided and fun way online may aid progress through self-regulated learning. In addition, the cross-language and cross-cultural exchange across Europe's SLs and deaf communities adds significant value to the project (cf. Kusters et al., 2024; Leeson and van den Bogaerde, 2020).

3.2. E-learning Platforms for SLs

Online learning platforms for sign languages have evolved from simple video repositories to interactive systems. Early work by Kelly et al. (2008) explored live feedback, laying important groundwork for later platforms. A relevant recent comparator is the SL-ReDu platform for learning GSL as an L2, which integrates SL recognition into a web-based environment for self-monitoring and objective learner assessment (Papadimitriou et al., 2025). Related multilingual platform work is represented by VisuoLab, a multilingual, -modal, and -functional platform designed for SL communities (Rathmann et al., 2024). Recent work also incorporates interactive elements (Wang, 2025), though comprehensive platforms integrating curriculum management, real-time feedback, and personalised instruction remain rare.

Recent work has also examined challenges for deaf students in e-learning environments (Aljedaani et al., 2023), highlighting the need for accessible platforms. Game-based approaches (e.g. Economou et al., 2020) combine SL learning with gamification elements, an approach VISTA-SL incorporates through achievement badges and progress tracking (see section 4.2).

3.3. Education Technologies

Vision and Sensor-Based Systems: Zhang et al. (2021) present a mobile phone-based system for Chinese Sign Language using point clouds, which are more lightweight than video streams. The app indicates to users whether they were correct or not, but does not provide additional feedback on what was incorrect. Truong et al. (2022) use MediaPipe (Lugaresi et al., 2019) with a gated recurrent unit model for Vietnamese Sign Language recognition. While effective, their use of a prosthetic arm for visualisation limits adoption potential.

Shao et al. (2020) describe an augmented reality SL teaching system with detailed feedback on sign production. Alam et al. (2024) present recent approaches for sign recognition in learning contexts, though without focus on explainable feedback.

Building on these foundations, VISTA-SL will go beyond binary classification, providing contextual assistance in the form of visual, textual and numerical feedback, based on real-time hand, face, and pose landmark detection (see section 5.1).

Avatar-Based and Immersive Systems: Phan et al. (2018, 2020) present an avatar-based system with multiple feedback modes including arrows for wrong positions, trajectory paths, and 'phantom visualisation' where teacher movements are superimposed on student recordings.

Immersive virtual reality (VR) environments have shown promise for engagement. Wang et al. (2023) implement a VR environment for learning numbers in ASL with game mechanics, finding higher user appeal than traditional methods. Quandt (2020), Quandt et al. (2022) and Kasapakis et al. (2024) describe VR systems using motion capture for sign language learning. While these immersive environments demonstrate research potential, their complex setup and high cost limit mainstream adoption. VISTA-SL addresses this by providing web-based access on commodity hardware to 3D avatar visualisations (see section 5.2).

AI and LLM-Based Tutoring Systems: Research on feedback for sign language learners predates current LLM-based systems. Huenerfauth et al. (2017) evaluated methods for presenting language feedback for student ASL videos, providing an important foundation for later computer-assisted feedback research. More recent work examines learner preferences for automatic feedback (Hassan et al., 2022), automated vocabulary assessment and learner perceptions (Holzknecht et al., 2024), and the automatic elaboration of linguistic annotations into learner-facing feedback (Battisti and Ebling, 2024). Related work on annotation for continuous Swiss German Sign Language (Battisti et al., 2024) and the recent dissertation of Battisti (2025) further highlight the growing focus on the analysis and assessment of L2 sign production. VISTA-SL will extend this line by introducing an LLM-based virtual instructor for text-based contextual coaching depending on learner progress and exercise performance (see section 5.3).

Surveys and Broader Context: Recent surveys now cover sign language processing more broadly, including recognition, translation, production, and datasets. Tan et al. (2024) review deep learning-based approaches to sign language processing, while Toshpulatov et al. (2025) provide a more recent overview spanning recognition, translation, production, and datasets. For sign language translation specifically, Shahin and Ismail (2024) survey the evolution from rule-based methods to transformer architectures. In feedback research, Paudyal et al. (2019, 2020) demonstrate benefits of explainable AI for sign language learning, while Hassan et al. (2022) investigate learner preferences for automatic feedback. Prior work on error taxonomies for computer-assisted language learning (Suri and McCoy, 1993) highlights the importance of categorising learner mistakes to enhance instructional feedback.

4. Curriculum

The VISTA-SL platform delivers curricula in four European sign languages: DGS, GSL, ISL and NGT. Content is developed by sign language educators and linguists at partner institutions following requirements gathered through focus groups with both deaf and hearing learners and deaf educators. It is designed to account for the needs of both L2M1 and L2M2 learners.

4.1. Content Structure and Types

The curricula follow a three-level hierarchical organisation of courses, modules, and lessons. Their content will include:

(a) (b)

Figure 1: Examples of VISTA-SL exercise feedback, given in DGS, for (a) good performance and (b) mixing up signs.

- Vocabulary acquisition through flashcards and isolated sign demonstrations
- Grammatical structures including non-manual markers and role-shifting
- Sentence-level content for real-life sign language interactions
- Signed dialogues between two people
- Illustration of sign variation due to regional and individual differences

On top of classical vocabulary topics (family, food, etc.) and interaction elements (introducing oneself, talking about the weather) and various semantic fields such as time, relationships or food, we include specific areas of interests, representing each country, such as sports events and car brands.

Exercises will involve activities such as identifying signs, understanding signed utterances, and reproducing signs. For sign reproduction, learners will be able to have their performance mirrored back to them, allowing them to practise before handing in recordings for evaluation. For certain aspects of signing, learners will also be able to practice using augmented reality feedback (see section 5.1).

4.2. Games and Gamification

A number of steps are being taken to make the learning process enjoyable and thus further motivate learners. These include immediate exercise feedback, progress tracking and games to practice content. Once again, input from the focus groups proved instrumental in refining these elements and aligning them with the needs of all user groups.

During exercises, users should receive immediate feedback. To enhance language immersion, system feedback can be given in the target language, e.g. through signed expressions that indicate correct or incorrect answers in a playful manner (see fig. 1). Furthermore, learners will be able

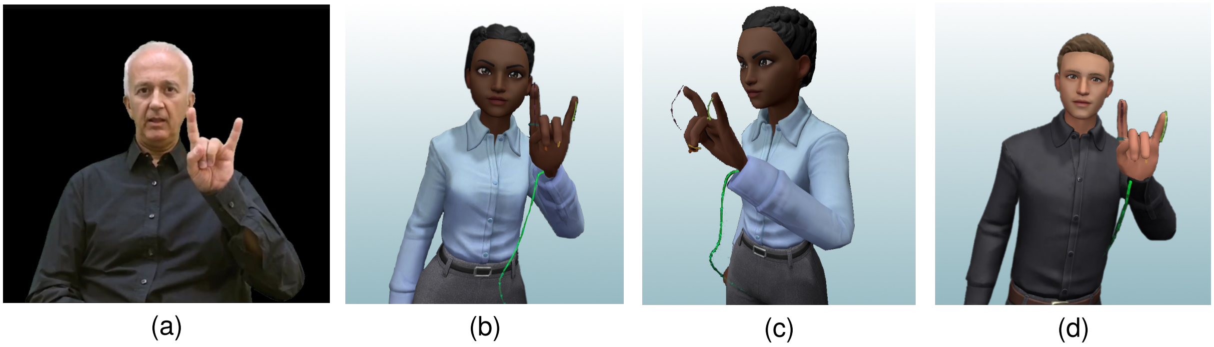

Figure 2: Avatar demonstrations for the GSL letter H (Eta): (a) reference video, (b–d) avatars with trajectory overlays, shown from various viewing angles.

to practice signs through augmented reality feedback (see section 5.1), which can give immediate visual and textual input on e.g. how to adjust their handshape to match that of the target sign. On completing exercises, users will receive progress badges and completion indicators (see section 6.2).

Several games will be provided to help learners practice, such as quizzes, memory, and fill-the-gap. These games will cover vocabulary practice, language understanding exercises and deaf culture content. In implementing these games, it was important to design them in a sign-centric manner, avoiding variants that relied on written language text to work. While sign-centric design is generally desirable for an immersive learning environment, it is particularly important for the deaf user group of the VISTA-SL platform, for whom both source and target language should be signed. Therefore, games like quizzes that involve a user's first language for instructions or answers would need to be able to also provide these as either text or sign video, depending on the user's own language.

4.3. Cultural Integration

The feedback from focus groups emphasised that deaf culture and sign languages are inextricably linked and should therefore not be taught in isolation from each other. The VISTA-SL curriculum accounts for this by including content on deaf culture and identities that will go alongside the linguistic material . Vocabulary lessons will also be accompanied by cultural context notes. Similarly, the selection of games (see section 4.2) will also cover ones that test users on matters of deaf culture.

5. Education Technologies

To assist learners in their practice sessions, the VISTA-SL platform will provide a number of interactive features leveraging language technologies, such as sign language recognition (section 5.1), sign language synthesis (section 5.2) and large language models (section 5.3). In this section, we describe some of these features to illustrate how these technologies will be used by the platform.

5.1. Augmented Reality Feedback

A typical challenge for learners of sign languages, especially those not used to the visual modality, is to reproduce signs accurately, e.g. using the correct handshape, orientation and movements (cf. Lerose, 2025). An augmented reality system with integrated sign recognition functionalities will give learners real-time feedback on their attempts, evaluating them against the reference material.

For instance, for handshape and orientation feedback, video from the user's webcam will be mirrored back, but overlaid with an augmented reality comparison between the user's hand and that of the reference. In addition, users will receive fine-grained feedback on individual parts of the handshape through both colour-coding of their hand's keypoints in the augmented image, as well as textual descriptions of what needs correcting.

Feedback for non-manual features - like question marking, negation, intensifiers and mouth gestures - will use tracking of facial markers such as eyebrow raise, mouth patterns, and head tilts. For signs involving motion, body part movement patterns will be processed to provide feedback. Information from these components will also be combined to provide general feedback on individual signs and sentences.

5.2. 3D Avatar System

Each sign or sentence in the curriculum material is represented by a video recording of a deaf L1 signer. To provide users with additional information, they will be able to show the same material performed by a virtual avatar, allowing them to view it from dynamically chosen viewing angles and zoom levels. Optional trajectory tracks of hand and arm motions will provide further assistance. These features can be seen in fig. 2, which shows the reference video

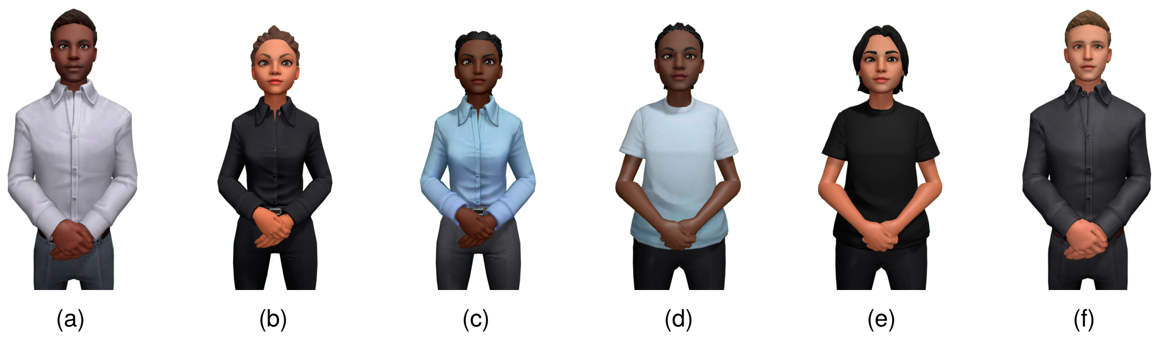

Figure 3: Different avatar appearances.

of a GSL signer fingerspelling the Greek letter H (Eta) and avatars from various viewing angles with trajectory overlays.

Following established best practice for sign language avatars (Krausneker and Schügerl, 2021; Kopf et al., 2023), users will be able to choose from a variety of avatar appearances and background options, as can be seen in fig. 3.

To ensure appropriate quality of the avatar performance while still scaling it to cover sufficient amounts of material, initial performances will be generated using pose and face keypoint estimations from the reference videos, which can then be then revised through an editor interface.

5.3. Virtual Instructor and Coaching

The VISTA-SL platform will also incorporate an LLM-based virtual instructor that provides personalised coaching based on learner context. The coaching system will access learner progress summaries—completion rates, average scores, recent performance, and recommended next lessons—to generate contextually relevant guidance. The coach can identify error patterns across lessons and provide targeted practice recommendations.

Given that the integration of sign language synthesis into generative model systems at production quality is still an open research challenge, the virtual instructor will focus on giving feedback in written form.

6. The VISTA-SL Platform

This section describes the VISTA-SL platform architecture (section 6.1), its learning management (section 6.2), accessibility (section 6.3), and privacy considerations (section 6.4).

6.1. Platform Architecture

The VISTA-SL platform follows a modular client-server architecture, shown in fig. 4, designed to integrate independently developed components while maintaining a cohesive user experience. This allows partner institutions to develop and integrate modules—AR tools, avatar system, LLM instructor, curricula—in parallel using their preferred technologies. The frontend prioritises low barriers to entry: users access the platform through standard web browsers on commodity hardware (laptop or tablet with webcam), without requiring specialised sensors or VR equipment.

The augmented reality feedback system will build on pre-computed reference landmarks extracted from expert demonstrations. Its scoring algorithm will use *Procrustes* analysis (Arvanitis et al., 2023) for shape comparison, applying weighted distance metrics that emphasise fingertips and key joint positions. The platform will use the *Performs* 3D avatar system developed by Universitat Pompeu Fabra (Valls-Garolera et al., 2025). Avatar animations will be created and edited using the web-based *Animics* tool (Ubieto et al., 2024; Pozo et al., 2025). The virtual instructor will provide a provider abstraction layer, supporting multiple LLM backends (commer-

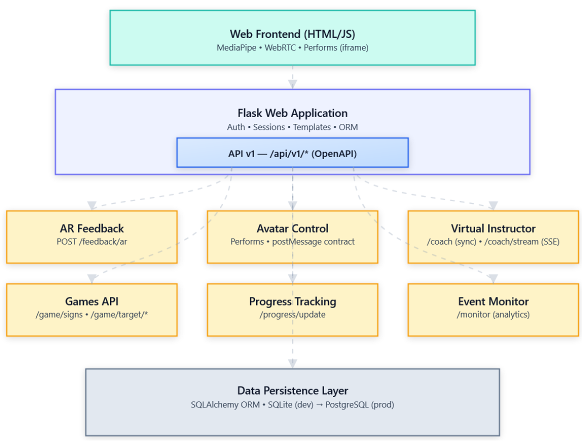

Figure 4: High-level architecture of the VISTA-SL platform, showing the web frontend, backend with core modules (AR Feedback, Avatar Control, Virtual Instructor, Games API, Progress Tracking), and data persistence layer.

cial APIs or locally-hosted open models) to ensure flexibility and avoid vendor lock-in.

6.2. Learning Management and Progress Tracking

The learning content follows a hierarchical structure of courses, modules, and lessons, enabling organised progression through sign language curricula. Each lesson combines reference videos showing expert demonstrations, 3D avatar animations, and interactive practice with AR feedback.

The progress tracking system records lesson completion status, performance scores, and timestamps, enabling both learner self-assessment and educator monitoring. A visual dashboard presents courses with progress indicators, animated video thumbnails, and completion badges, providing learners with clear visibility into their advancement.

6.3. Accessibility within VISTA-SL

The VISTA-SL platform is designed with users in mind whose first language may be either a signed or spoken language. Depending on the user's preferred modality, the interface will contain more written or signed content. For instance, while a speaker of German who is learning GSL will be shown German text for translations of GSL signs, a signer of DGS will be provided with DGS videos as translations instead.

The platform will be designed in coordination with our focus groups. It will also follow established web accessibility standards, such as the WCAG 2.1 guidelines[6]. These include incorporating keyboard navigation, screen reader compatibility, and sufficient colour contrast.

6.4. Privacy

Privacy in educational technology has gained increasing attention, particularly for systems processing video data. Existing sign language learning systems often require video upload or recording, raising concerns about data storage and potential misuse. VISTA-SL implements a privacy-preserving architecture where the video processing for self-paced learning occurs entirely client-side. For augmented reality feedback (section 5.1) only extracted landmark data—abstract skeletal representations—are transmitted for analysis, with no raw video stored on servers. The only instance where video is transmitted is when it is sent to a human teacher. This approach aligns with data minimisation principles while enabling effective feedback.

[6] https://www.w3.org/TR/WCAG21/

7. Conclusion

This paper presented VISTA-SL, an integrated e-learning platform for sign language education. The platform will provide materials for four different European sign languages and is designed both for people learning their first sign language and for signers wanting to learn another sign language. The curriculum of VISTA-SL, based on the institutional experience of several project partners, will cover beginner level vocabulary and phrases, as well as information on deaf culture and history. To support learners during self-guided practice, VISTA-SL will integrate a number of education features powered by language technologies, such as augmented reality feedback, 3D avatar demonstrations, and LLM-powered coaching. To support its integration with classes taught by sign language teachers, the platform will also provide interfaces for teachers to provide feedback on homework exercises submitted by students. The various components of the platform, such as the intelligibility and user acceptance of the avatar, will be evaluated throughout the run time of the project in coordination with our focus groups.

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- Hellenic Mediterranean University, Greece
- Stichting Koninklijke Kentalis, Netherlands
- Universitat Pompeu Fabra, Spain
- University of Hamburg, Germany
- Technological University Dublin, Ireland

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9. Bibliographical References

Md Shahinur Alam, Jason Lamberton, Jianye Wang, Carly Leannah, Sarah Miller, Joseph Palagano, Myles de Bastion, Heather L. Smith, Melissa Malzkuhn, and Lorna C. Quandt. 2024. ASL champ!: a virtual reality game with deep-learning driven sign recognition. *Computers & Education: X Reality*, 4:100059.

Wajdi Aljedaani, Rrezarta Krasniqi, Sanaa Aljedaani, Mohamed Wiem Mkaouer, Stephanie Ludi, and Khaled Al-Raddah. 2023. If online learning works for you, what about deaf students? emerging challenges of online learning for deaf and hearing-impaired students during COVID-19: a literature review. *Universal Access in the Information Society*, 22(3):1027–1046.

Filiz Altun. 2025. Analysis of the UNCRPD committee recommendations on the implementation of article 24 on the right to inclusive education. EASPD report, European Association of Service providers for Persons with Disabilities, Brussels, Belgium.

Nikolaos Arvanitis, Evangelos Sartinas, and Dimitrios Kosmopoulos. 2023. Procrustes-dtw: Dynamic time warping variant for the recognition of sign language utterances. In *2023 IEEE International Conference on Acoustics, Speech, and Signal Processing Workshops (ICASSPW)*, pages 1–5.

Alessia Battisti. 2025. *Analysis and Assessment of Continuous Swiss German Sign Language Production of Adult Learners*. Dissertation, University of Zurich.

Alessia Battisti and Sarah Ebling. 2024. Automatic annotation elaboration as feedback to sign language learners. In *Proceedings of the 18th Linguistic Annotation Workshop (LAW-XVIII)*, pages 46–60, St. Julians, Malta. Association for Computational Linguistics.

Alessia Battisti, Katja Tissi, Sandra Sidler-Miserez, and Sarah Ebling. 2024. Advancing annotation for continuous data in Swiss German Sign Language. In *Proceedings of the LREC-COLING 2024 11th Workshop on the Representation and Processing of Sign Languages: Evaluation of Sign Language Resources*, pages 163–174, Torino, Italy. ELRA Language Resources Association (ELRA) and the International Committee on Computational Linguistics (ICCL).

Kostas Blekos, Dimitrios Kosmopoulos, and Klimis Antzakas. 2026. A vision-based system for automated sign language teaching. *IEEE Transactions on Learning Technologies*, 19:182–195.

Deborah Chen Pichler and Elena Koulidobrova. 2015. Acquisition of sign language as a second language. In Marc Marschark and Patricia Elizabeth Spencer, editors, *The Oxford Handbook of Deaf Studies in Language*, Oxford Library of Psychology, chapter 14, pages 218–230. Oxford University Press.

Council of Europe. 2020. *Common European Framework of Reference for Languages: Companion Volume*. Council of Europe Publishing, Strasburg.

Aashaka Desai, Maartje De Meulder, Julie A. Hochgesang, Annemarie Kocab, and Alex X. Lu. 2024. Systemic biases in sign language AI research: A deaf-led call to reevaluate research agendas. In *Proceedings of the LREC-COLING 2024 11th Workshop on the Representation and Processing of Sign Languages: Evaluation of Sign Language Resources*, pages 366–377, Torino, Italy. ELRA Language Resources Association (ELRA) and the International Committee on Computational Linguistics (ICCL).

Daphne Economou, Melissa Russi, Ioannis Doumanis, Markos Mentzelopoulos, Vassiliki Bouki, and Jeffery Ferguson. 2020. Using serious games for learning British Sign Language combining video, enhanced interactivity, and VR technology. *Journal of Universal Computer Science*, 26(8):996–1016.

Klaudia Grote, Horst Sieprath, and Bastian Staudt. 2018. Deaf Didaktik? Weshalb wir eine spezielle Didaktik für den Unterricht in Gebärdensprache benötigen. *Das Zeichen*, 110:2–13.

Raychelle Harris, Heidi M. Holmes, and Donna M. Mertens. 2009. Research ethics in sign language communities. *Sign Language Studies*, 9(2):104–131.

Saad Hassan, Sooyeon Lee, Dimitris Metaxas, Carol Neidle, and Matt Huenerfauth. 2022. Understanding ASL learners' preferences for a sign language recording and automatic feedback system to support self-study. In *Proceedings of the 24th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '22)*, Assets '22. Association for Computing Machinery.

Franz Holzknecht, Sandrine Tornay, Alessia Battisti, Aaron Olaf Batty, Katja Tissi, Tobias Haug, and Sarah Ebling. 2024. Automated sign language vocabulary assessment: Comparing human and machine ratings and studying learner perceptions. *Language Assessment Quarterly*, 21(3):245–265.

Matt Huenerfauth, Elaine Gale, Brian Penly, Sree Pillutla, Mackenzie Willard, and Dhananjai Hariharan. 2017. Evaluation of language feedback methods for student videos of American Sign Language. *ACM Transactions on Accessible Computing*, 10(1).

Ege Karar, Klaudia Grote, and Horst Sieprath. 2017. Deaf didactics: Why it is not enough just to teach bilingual. Presentation at the 3rd International Conference of the World Federation of the Deaf.

Vlasios Kasapakis, Elena Dzardanova, Spyros Vosinakis, and Androniki Agelada. 2024. Sign language in immersive virtual reality: design, development, and evaluation of a virtual reality learning environment prototype. *Interactive Learning Environments*, 32(10):6657–6671.

Daniel Kelly, John McDonald, and Charles Markham. 2008. A system for teaching sign language using live gesture feedback. In *2008 8th IEEE International Conference on Automatic Face & Gesture Recognition*, pages 1–2, Amsterdam, Netherlands. IEEE.

Maria Kopf, Rehana Omardeen, and Davy Van Landuyt. 2023. Representation matters: The case for diversifying sign language avatars. In *Proceedings of the Eighth International Workshop on Sign Language Translation and Avatar Technology*, pages 1–5, Rhodes Island, Greece. IEEE.

Verena Krausneker and Sandra Schügerl. 2021. Best practice protocol on the use of sign language avatars. Technical report, Universität Wien, Vienna, Austria.

Annelies Kusters, Erin Moriarty, Amandine le Maire, Sanchayeeta Iyer, and Steven Emery. 2024. *Deaf Mobility Studies: Exploring International Networks, Tourism, and Migration*. Gallaudet University Press, Washington, DC.

Annelies Maria Jozef Kusters, Maartje De Meulder, and Dai O'Brien. 2017. Innovations in deaf studies: Critically mapping the field. In Annelies Kusters, Maartje De Meulder, and Dai O'Brien, editors, *Innovations in Deaf Studies: The Role of Deaf Scholars*, Perspectives on Deafness, pages 1–53. Oxford University Press, Oxford.

Paddy Ladd. 2022. *The unrecognized curriculum: seeing through new eyes: deaf cultures and deaf pedagogies*. DawnSignPress, San Diego.

Lorraine Leeson and Beppie van den Bogaerde. 2020. (What we don't know about) sign languages in higher education in Europe: Mapping policy and practice to an analytical framework. *Sociolinguistica*, 34(1):31–56.

Luigi Lerose. 2025. *Improving Your British Sign Language: A Guide to Proficient Use*. Cambridge University Press, Cambridge.

Camillo Lugaresi, Jiuqiang Tang, Hadon Nash, Chris McClanahan, Esha Uboweja, Michael Hays, Fan Zhang, Chuo-Ling Chang, Ming Guang Yong, Juhyun Lee, Wan-Teh Chang, Wei Hua, Manfred Georg, and Matthias Grundmann. 2019. MediaPipe: A framework for building perception pipelines. Preprint. arXiv:1906.08172.

Elizabeth S. Mathews. 2020. Signs of equity: Access to teacher education for deaf students in the Republic of Ireland. *Sign Language Studies*, 21(1):68–97.

Christiane Metzger. 2008. *Lernstrategien erwachsener L2-Lerner der Deutschen Gebärdensprache: eine Analyse auf der Grundlage handlungstheoretischer und kognitionswissenschaftlicher Modelle*. Ph.D. thesis, Narr, G, Tübingen.

Katerina Papadimitriou, Gerasimos Potamianos, Galini Sapountzaki, Theodoros Goulas, Eleni Efthimiou, Stavroula-Evita Fotinea, and Petros Maragos. 2025. Greek sign language recognition for an education platform. *Universal Access in the Information Society*, 24:51–68.

Prajwal Paudyal, Ayan Banerjee, and Sandeep Gupta. 2020. On evaluating the effects of feedback for Sign language learning using Explainable AI. In *Companion Proceedings of the 25th International Conference on Intelligent User Interfaces*, IUI '20 Companion, pages 83–84. Association for Computing Machinery.

Prajwal Paudyal, Junghyo Lee, Azamat Kamzin, Mohamad Soudki, A. Banerjee, and S. Gupta. 2019. Learn2Sign: Explainable AI for Sign Language Learning. In *Joint Proceedings of the ACM IUI 2019 Workshops – Workshop on Explainable Smart Systems - ExSS*.

Han Duy Phan, Kirsten Ellis, and Alan Dorin. 2018. MIC, an interactive sign language teaching system. In *Proceedings of the 30th Australian Conference on Computer-Human Interaction*, OzCHI '18, pages 544–547. Association for Computing Machinery.

Han Duy Phan, Kirsten Ellis, Alan Dorin, and Patrick Olivier. 2020. Feedback strategies for embodied agents to enhance sign language vocabulary learning. In *Proceedings of the 20th ACM International Conference on Intelligent Virtual Agents*, Iva '20, pages 1–8. Association for Computing Machinery.

Jaume Pozo, Eva Valls-Garolera, and Víctor Ubieto. 2025. Animics. https://github.com/upf-gti/animics/. Last commit: 25-03-2026, in development.

Lorna Quandt. 2020. Teaching ASL signs using signing avatars and immersive learning in virtual reality. In *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility*, pages 1–4, Online. Association for Computing Machinery.

Lorna C. Quandt, Athena Willis, Melody Schwenk, Kaitlyn Weeks, and Ruthie Ferster. 2022. Attitudes toward signing avatars vary depending on hearing status, age of signed language acquisition, and avatar type. *Frontiers in Psychology*, 13:730917.

Christian Rathmann, Ronice Müller de Quadros, Thomas Geißler, Christian Peters, Francisco Fernandes, Milene Peixer Loio, and Diego França. 2024. VisuoLab: Building a sign language multilingual, multimodal and multifunctional platform. In *Proceedings of the LREC-COLING 2024 11th Workshop on the Representation and Processing of Sign Languages: Evaluation of Sign Language Resources*, pages 14–21, Torino, Italy. ELRA Language Resources Association (ELRA) and the International Committee on Computational Linguistics (ICCL).

Krister Schönström and Ingela Holmström. 2022. L2M1 and L2M2 acquisition of sign lexicon: The impact of multimodality on the sign second language acquisition. *Frontiers in Psychology*, 13.

Nada Shahin and Leila Ismail. 2024. From rule-based models to deep learning transformers architectures for natural language processing and sign language translation systems: Survey, taxonomy and performance evaluation. *Artificial Intelligence Review*, 57:271.

Qijia Shao, Amy Sniffen, Julien Blanchet, Megan E. Hillis, Xinyu Shi, Themistoklis K. Haris, Jason Liu, Jason Lamberton, Melissa Malzkuhn, Lorna C. Quandt, James Mahoney, David J. M. Kraemer, Xia Zhou, and Devin Balkcom. 2020. Teaching American Sign Language in mixed reality. In *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, volume 4, pages 152:1–152:27, Online. ACM.

Linda Z. Suri and Kathleen F. McCoy. 1993. A methodology for developing an error taxonomy for a computer assisted language learning tool for second language learners. Technical Report 93-16, University of Delaware, Newark, DE, USA.

Sihan Tan, Nabeela Khan, Zhaoyi An, Yoshitaka Ando, Rei Kawakami, and Kazuhiro Nakadai. 2024. A review of deep learning-based approaches to sign language processing. *Advanced Robotics*, 38(23):1649–1667.

Mukhiddin Toshpulatov, Wookey Lee, Jaesung Jun, and Suan Lee. 2025. Deep learning pathways for automatic sign language processing. *Pattern Recognition*, 164:111475.

Nghe-Nhan Truong, Truong-Dong Do, Thien-Sang Le Nguyen, Minh-Thien Duong, Thanh-Hai Nguyen, and My-Ha Le. 2022. A vision-based hand-sign language teaching system using deep neural network: Methodology and experiments. In *2022 International Workshop on Intelligent Systems (IWIS)*, pages 1–6.

Víctor Ubieto, Jaume Pozo, Eva Valls, Beatriz Cabrero-Daniel, and Josep Blat. 2024. Sign language synthesis: Current signing avatar systems and representation. In Andy Way, Lorraine Leeson, and Dimitar Shterionov, editors, *Sign Language Machine Translation*, number 5 in Machine Translation: Technologies and Applications, pages 247–266. Springer, Cham.

Eva Valls-Garolera, Jaume Pozo, , and Carolina del Corral. 2025. Performs. https://github.com/upf-gti/performs/. Last commit: 25-03-2026, in development.

J. Wang. 2025. *Human-Centred American Sign Language Learning: Effects of Interface Modality, Game Mechanics, and Artificial Intelligence-Based Diagnostic Guidance*. Doctoral thesis, Durham University.

Jindi Wang, Ioannis Ivrissimtzis, Zhaoxing Li, Yunzhan Zhou, and Lei Shi. 2023. Exploring the potential of immersive virtual environments for learning American Sign Language. In *Responsive and Sustainable Educational Futures*, pages 459–474. Springer.

Bencie Woll. 2012. Second language acquisition of sign language. In *The Encyclopedia of Applied Linguistics*. John Wiley & Sons.

Yanxiao Zhang, Yuecong Min, and Xilin Chen. 2021. Teaching Chinese Sign Language with a smartphone. *Virtual Reality & Intelligent Hardware*, 3(3):248–260.