CoSignPlay: A Collaborative Approach to Learning Non-Manual Signs in ASL for Hearing Families with Deaf Children

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Abstract

Hearing parents of young deaf and hard-of-hearing (DHH) children often lack essential skills in American Sign Language (ASL), which can lead to socio-emotional isolation and language deprivation for DHH children. Learning ASL, especially non-manual signs (NMS), can be challenging for hearing individuals due to cognitive and cultural barriers. Inspired by "group narrative", a collaborative storytelling activity commonly seen in the Deaf communities, we propose a novel collaborative learning approach named CoSignPlay. It aims to support NMS learning among hearing family members and DHH children by allowing two players to jointly control NMS and manual signs (MS) of a 3D avatar in a game context. We adopted the design probe and technology probe methods to explore the unique opportunities and challenges of CoSignPlay. We conducted an interview study with six hearing parents of young DHH children, six ASL instructors, and two speech-language pathologists in early education programs. Findings revealed positive feedback to CoSignPlay in addressing key cognitive and cultural challenges of NMS learning for novice hearing learners, along with insightful critiques and suggestions for improvements. We present in-depth discussions of design implications and guidelines for future collaborative learning technologies on NMS.

CCS Concepts

• **Human-centered computing → Human computer interaction (HCI)**.

Keywords

American Sign Language, non-manual signs, avatar, collaborative learning, deaf and hard of hearing

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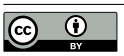

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1 Introduction

Imagine sitting at the dinner table surrounded by your loved ones, with conversations and laughter floating in the air, yet you cannot understand a word. This so-called "Dinner Table Syndrome" [44] is an everyday reality for many Deaf and Hard of Hearing (DHH) children in hearing families who do not use sign language. This kind of social and emotional isolation is widespread - more than 90% of DHH children in the United States are born to hearing families [80], and for most of these parents, their child is the first DHH person they've ever met. Without a fully accessible sign language environment at home, DHH children are at risk of language deprivation, which can lead to atypical neural development, cognitive delays, and lifelong mental health challenges [39, 74]. Pediatric research increasingly points to the crucial needs for parental involvement in sign language use in prevention against language deprivation among DHH children [48]. Studies in American Sign Language (ASL) acquisition in early childhood underscore that even if parents aren't fluent signers, children can still learn sign language by working through the inconsistencies in how their parents sign [107]. When families learn sign language together with their DHH child, there is increased communication within the family [90].

Learning sign language presents unique ***cognitive challenges***, especially for those new to visual language. Unlike spoken language, where sounds are produced sequentially, sign language requires the simultaneous processing and production of both manual signs (MS) (e.g., hand shapes, movements, and locations) and non-manual signals (NMS) (e.g., facial expressions and head movements). A small change in head movement, for example, can completely change the meaning of a sign [53, 78, 93, 127]. This multi-channel visual communication involves increased neural resources [19, 33], making integration of multiple streams of visual information in real time particularly demanding. In addition, hearing individuals may face unique ***cultural challenges*** when learning NMS - an integral part of sign language but commonly overlooked due to widespread misconceptions that sign language is solely a "language of the hands"

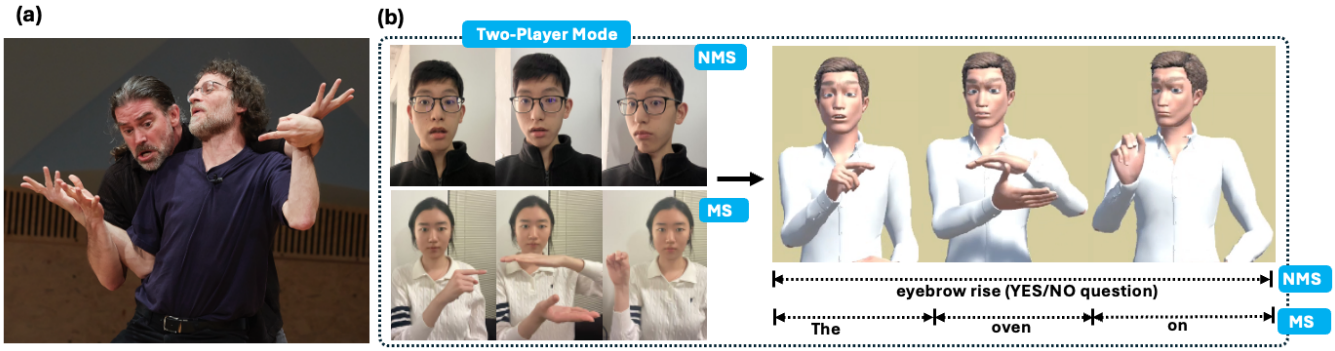


Figure 1: Overall design concept: (a) an example of two Deaf signers engage in a group narrative activity. The person standing in front is responsible for NMS, while the person behind performs the MS (or jointly performs it with the person in front)[1]; (b) overall concept illustration of CoSignPlay involving two ASL learners who collaboratively control the 3D avatar. In this work, we adopted the version of group narrative, where one person controls NMS and the other controls MS to simplify the collaborative signing activity. The avatar tracks NMS of the person on top, and MS of the person below.

[93]. Those who are from cultures where facial expression is not commonly used in spoken communication could feel embarrassed or uncomfortable when adapting to NMS in sign language. Research shows that learners with a Latino background often exhibit greater proficiency in producing NMS compared to other American groups [78]. Additionally, women tend to use facial expressions more frequently and noticeably than men [30, 76, 117], who often suppress facial expressions, particularly those deemed "weak" [41].

In the Deaf community, playful Deaf cultural activities are used to support language learning and socialization. A unique form of Deaf experience called "group narrative", is a commonly seen group activity among DHH children and social gathering at Deaf communities and schools [25, 27, 102]. As shown in Fig. 1(a), the activity requires two signers to collaboratively perform storytelling activities. The person standing in front is responsible for NMS, while the person behind performs the MS (or jointly performs it with the person in front).

Inspired by the group narrative activity from the Deaf community, we propose a novel collaborative approach named CoSignPlay (Fig. 1(b)). We adopted the version where one person controls NMS and the other controls MS to simplify the collaborative signing activity. The essential design concept of CoSignPlay is allowing two persons collaborative control a 3D virtual avatar, who serves as an ASL interpreter to help a Deaf game character to complete social tasks (e.g., help a Deaf chef to bake a cake for the customer, following the instructions from a spoken co-worker). The NMS produced by one player, and MS by another player are jointly mapped to the 3D avatar. We hypothesize two unique benefits of CoSignPlay in addressing the cognitive and and cultural challenges faced by novice hearing learners for NMS in ASL, especially members of hearing families with young DHH children. First, by letting novice ASL learners focus on either MS or NMS at a time, it may help reduce their cognitive load by offloading parts of cognitive process to individual learners, as shown in prior studies of collaborative learning [32, 60]. Second, the light-hearted and judgment-free avatar control between family members may also help them feel less self-conscious, as shown in avatar-related studies [23, 57]. This may result in reducing cultural barriers for NMS learning.

While emerging work of learning technologies provides valuable insights into using games and 3D avatars to support sign language learning [4, 10, 13, 95–97], there remains a critical research gap in collaborative avatar-based social games to supporting NMS learning for novice hearing learners, especially for hearing parents with DHH children and other family members. To better understand the design space of collaborative signing in achieving the above goal, we conducted a design and technology probe study of CoSignPlay. We interviewed six hearing parents of DHH children aged 6 months to 5 years old, six ASL teachers for adult learners, and two Speech-language pathologists (SLPs) in early childhood education programs. Key research questions of this study are:

- RQ1: What are the opportunities and challenges for hearing parents to learn NMS in ASL?
- RQ2: What are the affordances and limitations of the design concept of human-controlled avatar signing game for NMS learning?
- RQ3: What are the affordances and limitations of the design concept of collaboratively-controlled avatar signing for NMS learning?

Our findings highlight the multi-faceted challenges that hearing parents experience in learning ASL, limited availability of learning resources, as well as valuable insights into collaborative learning and teaching experiences. We identified several potential benefits of the CoSignPlay concept, centered around (1) socio-cultural benefits – strengthening family bonding, reducing self-awareness, increasing motivation, and aligning with Deaf culture; (2) cognitive benefits – reduced cognitive load, the value of peer feedback; and (3) practical benefits – promoting self-learning, and emphasizing the importance of NMS. The findings also reveal key limitations, including naturalness and synchronization of the joint avatar movements, as well as preservation of holistic signing in ASL. The key contribution of this paper are three-fold:

[1]Peter Cook and Kenny Lerner. *Flying Words Project*. 2021. https://www.deafpetercook.com/flying-words-project. Accessed July 10, 2025.

- First, we propose a novel avatar-based collaborative signing approach in supporting NMS learning for hearing families with DHH children.
- Second, we provide insightful design implications, including family-centered NMS learning, balancing holistic signing with cognitive scaffolding, and bridging ASL learning with the Deaf culture and community.
- Third, we propose key design guidelines for future learning technologies, including considerations for avatar control, customizable learning experiences, and inclusive design for young and DHH children.

2 Related work

2.1 Deaf culture and NMS in ASL

Languages and cultures are strongly interconnected, and this is also true for sign languages. Many deaf individuals identify themselves as part of a distinct cultural and linguistic minority, brought together by shared language, common values, and life experiences [9, 14, 15, 65]. Sign languages are a central component of Deaf cultures, functioning as a cultural and communicated role in Deaf culture and identity [14, 15, 29]. It involves MS (e.g., hand movement) and NMS (e.g., facial expressions) [93, 104]. NMS are essential for fully comprehending many signs and can significantly alter the meaning of individual signs [89]. For example, the signs for "CLEAN" and "VERY CLEAN" are only differentiated by the head movements in NMS. Therefore, NMS should be treated like other parts of grammar in ASL and not just signing "style" [24].

There are various grammatical functions of NMS in sign languages, such as lexical, morphological, and syntactic roles [93]. Lexical NMS play an important role in the phonological structure of signs [126]. For example, the ASL sign for "NOT YET" includes a hand gesture combined with the tongue touching the lower lip and a head rotation from side to side. Without these NMS, the sign could be misunderstood as "LATE" [1, 69]. Morphological NMS conveys information about semantically relevant word structure by modifying or adding grammatical meaning to MS [31, 93]. For example, facial expressions and body posture can show degrees of size or intensity, with stronger expressions used to indicate comparative forms like "small x" or "big x" [93]. Syntactic NMS helps define sentence types, such as Yes/No questions, and Negation and affirmation [9, 86, 93]. For example, in the frequently used Yes/No question "WILL YOU HELP ME?", the signer raises their eyebrows, while the same MS with a neutral face means "YOU HELP ME." [118, 134]. Therefore, NMS serve a range of grammatical functions.

2.2 Challenges of learning NMS

Learning or recognising NMS is tough [3, 24, 91]. Previous study found that while hearing learners could comprehend NMS for question forms (e.g., Yes/No questions) and sentential and lexical negation, they struggle to produce them as effectively as native ASL users [77]. Unlike MS, NMS have very subtle and complex properties [93, 127]. Ichida [52, 53] found that variations in head position and movement can affect meaning in sign language. For example, a quick sideways head jerk during "BEAUTIFUL" in "HEY, SEE BEAUTIFUL BIRD THERE" may be misread as negation, leading to the unintended meaning "NOT BEAUTIFUL" [46]. Therefore, these subtle yet grammatically essential differences are easily missed by novice or untrained learners.

Furthermore, ASL learners often face cultural norms and cognitive challenges. First, cultural norms may complicate the process of learning NMS. Learners often feel embarrassed using certain NMS, especially when expressions seen as rude in English are natural in ASL [78]. For example, furrowed brows in WH-questions may be misread as anger due to universal emotional cues [125]. Some ASL teachers also observed that minority groups, particularly Latinos, often exhibit greater proficiency in producing NMS compared to other American groups [78]. The additional cognitive load of NMS might also make learners feel difficulty. Unlike spoken language, where sounds are produced sequentially, NMS often occur at the same time as MS, making it challenging for people to decode all elements simultaneously [79]. Neurologists explored that when signers integrate NMS and MS, additional neural resources are recruited [19, 33]. Specifically, Signs with non-manual features lead to greater activation in specialized brain regions such as the superior temporal sulcus (STS) and inferior frontal gyrus (IFG) compared to manual-only signs [19]. This extra activation implies that when learners simultaneously coordinate NMS with MS, demanding more cognitive effort as NMS elements add more complexity. Cognitive overload theory [112], which emphasizes that learning suffers when too much information is processed at once and working memory becomes overwhelmed, also help explain this phenomenon. Therefore, for ASL learners, simultaneously encoding and interpreting MS and NMS can make learning more challenging.

2.3 ASL learning technologies

Assistive educational technology, such as games and avatars [4, 10, 13, 97, 106, 108, 131], offer new opportunities to enhance ASL learning. Aligning with the Experiential Learning Theory, which emphasizes the value of hands-on experiences and reflection [63], games are recognized as powerful tools for facilitating language learning and developmental processes [26, 36]. Gamified sign language instruction provides engaging and practical opportunities, enabling learners to learn and apply their knowledge and skills in a relaxed, enjoyable environment [123]. ASL learning games like PopSign [108], SignCueQuest [106], CopyCat [131], ASL Sea Battle [13] have advanced ASL education. For example, CopyCat combines gameplay with real-time feedback through a game character that moves with correct signs and pauses with incorrect ones [131].This synchronized feedback helps learners identify and correct mistakes, supporting more accurate ASL performance [42, 47].

Existing research recognizes the critical role of signing avatars in ASL learning [2, 4, 12, 55, 97]. Avatar-based systems improve content comprehension for DHH students by delivering accessible sign language instruction [55, 58, 66, 128], while also providing greater engagement, real-time multi-angle content, and a more realistic, game-like experience compared to traditional classrooms and digitized signer videos [12, 75, 97]. With these benefits, Alam et al. [4] developed a VR game that teaches ASL through immersive interaction with a signing avatar and real-time deep learning feedback. The avatar models pre-recorded signs from native ASL signers. Learners mimic the signs; correct hand movements advance to the next, while errors trigger repetition with head-shake feedback.

This interactive and accessible signing avatar offers an immersive, semi-realistic approach to learning a new sign language [4]. While these game and avatar based systems offer insightful guidance for creating engaging ASL learning experiences, most of them only focus on MS learning, with NMS learning under-explored.

2.4 Collaborative Deaf activity and collaborative learning

Collaborative learning involves two or more individuals working together to build knowledge or skills through interaction, information sharing, and joint problem-solving [6, 111]. In spoken language education, games like ToneWars [34], Crystallized [28], Trace Effects [8] engage learners in collaborative tasks. For example, ToneWars [34] connects second language learners with native speakers to practice tone recall, perception, and production in a collaborative game. Research shows that such technology-enhanced collaboration enriches language input resources, expands learning opportunities and activities, and increases engagement [7, 59, 64, 110, 116]. These outcomes align with social constructivist and sociocultural theories, which emphasize learning through interaction, mutual support, and guidance from more knowledgeable individuals [110, 121]. However, most ASL learning games lack collaborative features, missing opportunities for shared learning - which could be particularly beneficial for hearing families with DHH children. Research shows that parent-child collaborative learning, such as shared book reading, can improve children's learning outcomes like reading fluency [109]. Therefore, CoSignPlay aims to explore the potential opportunities or challenges when people collaboratively learn sign language.

In the Deaf community, there is a co-signing activity in which one individual handles NMS from the front while another, standing behind, performs MS, or jointly performs them with the front signer (Fig 1(a)) [25, 27, 102]. This is a creative way to provide entertainment, enhance social interaction, and improve peer communication through synchronized collaboration. Similarly, previous studies has shown that cooperative, time-synchronized games, such as "Rock Band" [84], Yamove! [54], and LAGH [22], can enhance social engagement. Given that ASL inherently requires coordination between MS and NMS, this study aims to investigate a novel collaborative learning experience that enables two players to perform MS and NMS together in a synchronized, game-like setting. Many studies started to investigate the potential of co-embodiment on a single avatar from multiple users [62, 68, 94, 133]. For example, a study shows that a co-embodied avatar segmented by body parts offers a novel experience compared to traditional drum learning [94]. Therefore, co-signing on a virtual avatar offers a novel learning activity where family members and children take turns controlling NMS and MS each time. They learn and communicate by engaging with each other to manipulate the performance of the virtual avatar. For DHH children, this approach aligns with their natural learning process, as research shows they distinguish NMS and MS early on, articulating them sequentially rather than simultaneously [5, 61, 98, 99]. For hearing family members, co-signing reduces cognitive load by allowing focus on one sign component at a time, whereas managing both NMS and MS simultaneously increases cognitive demands and may hinder learning [112]. Our findings will deepen understanding of the time-synchronized movements mechanism in supporting language learning that involves parallel linguistic signals including ASL.

3 CoSignPlay - design concept and prototyping

We propose CoSignPlay, which serves as a design and technology probe [37, 38] to facilitate the exploration of the design space of playful and family-centered NMS learning experiences. CoSignPlay includes the overall game concept of human-controlled avatar signing in social game scenarios (Section 3.1), and the collaboratively-controlled avatar signing option where one player contributes to NMS and another contributes to MS (Section 3.2) . We will describe the key design elements and corresponding rationale.

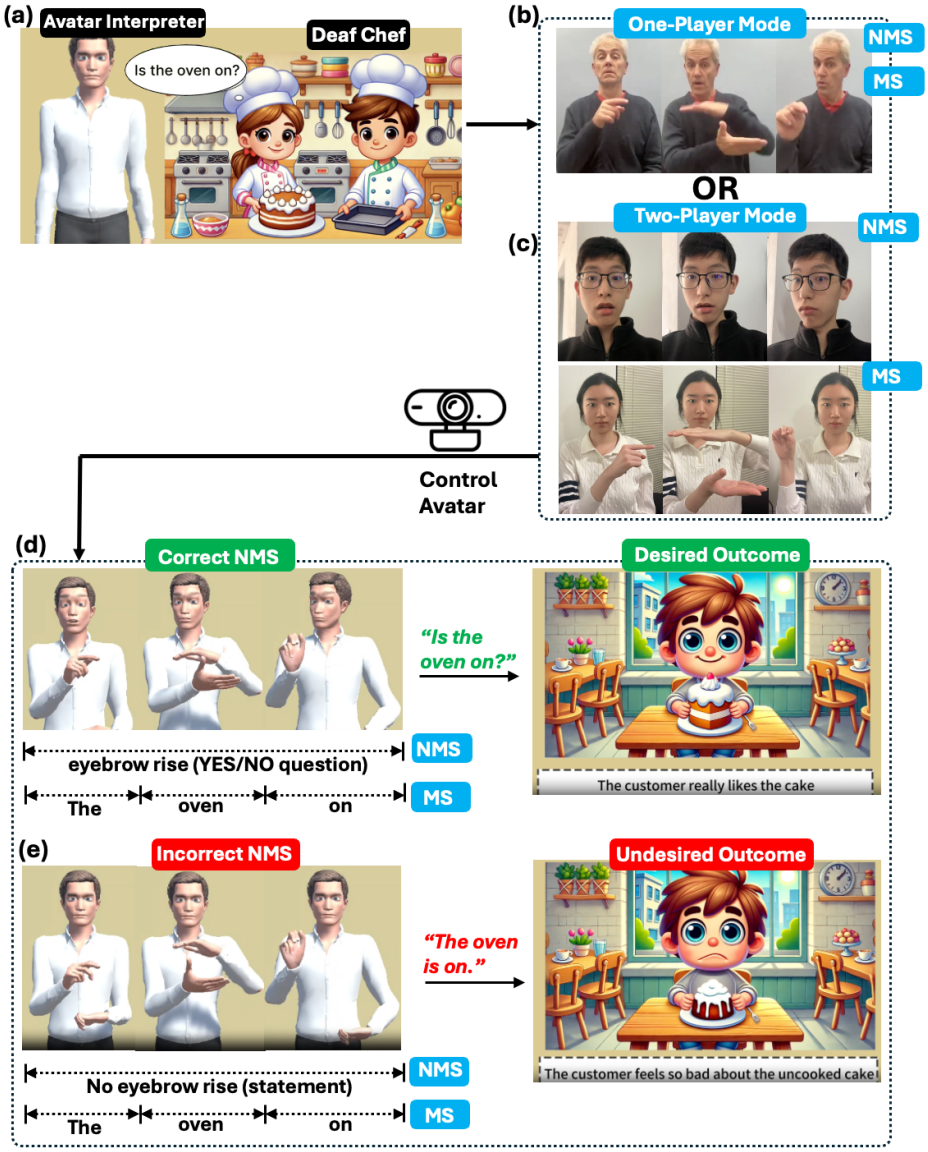
3.1 Human-controlled avatar signing game concept

3.1.1 Design concept. CoSignPlay is designed to involve ASL learner(s) in role-play as an ASL interpreter to help a deaf individual to handle everyday social interactions with other English-speaking characters in a game. Fig. 2(a) illustrates a game scenario in a restaurant where the deaf chef's co-worker asks him a question - "Is the oven on?". To help the deaf chef succeed in the cooking task, in the one-player mode, the player needs to control the 3D avatar to sign the question - the avatar mirrors the player's NMS and MS (Fig. 2(b)). In the two-player mode, two players jointly control the 3D avatar (Fig. 2(c))(see details in the next section). If the player produces the ASL sentence correctly for both MS and NMS (eyebrow rise for Yes/No question) (Fig. 2(d)), the deaf chef will understand his co-worker correctly and turn on the oven. This leads to the desired game outcome - the cake is well baked and the customer is happy. Otherwise, if the player doesn't produce the ASL correctly, for example, ignores eyebrow rise, then the deaf chef will misunderstand the question as a statement, and not turn on the oven. This will lead to the undesired outcome - the customer is unhappy because the cake is not well baked (Fig. 2(e)).

3.1.2 Design rationale. This overall game design concept is created to enhance NMS learning experiences by (1) increasing awareness of the importance of NMS for novice ASL learners; (2) embedding learning within everyday social scenarios; (3) having human-controlled avatar signing to offer interactive, real-time feedback and engagement.

Social scenarios. According to Situated Learning Theory, learning is "naturally tied to authentic activity, context, and culture" [18]. Integrating social context into educational games creates a more authentic learning environment, helping learners acquire language more effectively through real-life situations [88]. Moreover, by engaging in role-play activities based on everyday social scenarios, learners gain insight into how language functions in real communicative settings, making it easier to apply their skills in daily interactions [103]. Thus, CoSignPlay game scenario is set in a daily-life context—specifically, a restaurant setting—featuring two characters: Amy (hearing) and Tom (DHH). They collaboratively manage the restaurant, encouraging players to use ASL in socially embedded ways. CoSignPlay incorporates four basic types of NMS that are mentioned in the introduction, as they represent the most common and essential uses of NMS [9, 86, 93, 126]: Yes/No question

Figure 2: An illustration of the human-controlled avatar signing game concept.



("Is the oven on?"), Negation ("I don't need tomatoes because of an allergy"), Degree ("A large pizza or a larger pizza?"), and Lexical ("I want vanilla ice cream").

Human-controlled signing avatars. Many avatar-based technology studies, such as tuniSigner [11] and SAIL [4, 97], show the great opportunities for improving the learning performance of DHH students. However, the avatars used in previous studies primarily act as the model role where the avatar's movement is programmed or developed from the recording of ASL teachers. Observing an avatar's movements from a third-person perspective may introduce cognitive errors when learners attempt to replicate these movements observed in the avatar's body coordinates [62, 92]. Such errors could impede learners' ability to accurately understand and execute the correct movement patterns, ultimately diminishing the efficiency of the learning process [62, 92]. Moreover, Experiential Learning Theory emphasizes that learning through hands-on activities and reflection benefits the learning outcomes [63]. Therefore, CoSignPlay introduces the mirroring system where the avatar's NMS and MS movements are controlled by the user(s)' movements, allowing observation from a first-person perspective.

3.2 Collaboratively-controlled avatar signing

3.2.1 Design concept. Inspired by the rich tradition of "group narrative" [102] deeply rooted in the American Deaf culture, we proposed the collaboratively-controlled avatar signing concept to further explore new design opportunities and limitations of collaborative

NMS learning experiences that engage hearing family members and DHH children. As shown in Fig. 2(c), CoSignPlay provides a two-player mode where two players jointly control the avatar ASL signing - the NMS produced by one player (top), and MS by another player (bottom) are jointly mapped to the 3D avatar. This design reflects the two-person ASL performance commonly seen at social gatherings of deaf individuals, where the person at the front controls NMS and other people standing behind controls MS.

3.2.2 Design rationale. This collaborative-controlled avatar concept is meant to provide new NMS learning experiences that (1) turn ASL learning into a playful family activity engaging family members with various ASL abilities; and (2) reduce cognitive load for novice ASL learners by allowing them to focus on MS and NMS respectively when learning and practicing ASL.

Family-centered ASL learning. When families learn sign language together with DHH child, it enhances family communication and supports the child's age-appropriate vocabulary development [20, 90]. The active parental involvement in the home environment has shown especially strong potential for improving learning outcomes, often having a greater impact than involvement within the school setting [35, 45]. Family-centered learning often makes ASL acquisition more interactive and enjoyable, providing a fun and low-pressure environment for practice [113]. This approach fosters more effective communication and strengthens family bonds [85]. Therefore, CoSignPlay is designed to enable hearing family members and DHH children to learn ASL together.

Offload MS and NMS into two player. According to cognitive load theory [112], which suggests that learning is hindered when multiple types of information are processed at the same time, and empirical research showing that producing MS and NMS simultaneously increases cognitive effort [19, 33], the need to encode MS and NMS together may present challenges for learners. Research found that collaborators can offload parts of the task to each other, reducing each person's burden and risk of overload and allowing the construction of better knowledge structures [32, 60]. Therefore, offloading MS and NMS to two players may reduce the cognitive load and achieve better learning outcome.

3.3 Implementation of human-controlled avatar signing

We created a working prototype of a human-controlled avatar signing element of CoSignPlay. The system is composed of a pipeline that tracks MS from one player, and NMS from a second player, and maps them to one avatar.

For manual signing, we use MediaPipe Holistic provided in the mediapipe Python package (version 0.10.14) to extract 3D landmarks from the user's body and both hands from a real-time webcam stream. The landmarks are filtered with a One Euro Filter to reduce noise while maintaining responsiveness. The processed coordinates are serialized into JSON format and transmitted via UDP to a Unity receiver. In Unity, the hand joint coordinates are mapped to the avatar's hand rig to define bone directions. Wrist positions are set from the decoded landmark positions, and inverse kinematics (IK) is applied to the shoulder and elbow using Unity's Animation Rigging package for natural arm posture.

Facial movements and head orientation are tracked using MediaPipe Face Landmarker, which outputs 468 facial landmarks and 52 blendshape coefficients for facial movements. The results are passed through a One Euro Filter with conservative parameter settings, stabilizing the output without visibility distorting the signs. The facial landmarks are used to compute head rotation in Unity, and the blendshape coefficients are scaled and applied to avatar's facial rig, enabling expressive cues like emotion and mouthing.

As all interviews were conducted remotely via Zoom, we used Open Broadcaster Software (OBS) to capture participants' video feed and redirected it into the motion tracking system. This working prototype was used as a technology probe to elicit reliable feedback from stakeholders with the core concept of collaborative ASL signing. Therefore, sign recognition and real-time feedback are not implemented in the working prototype.

4 Research Method

This study adopted the design probe method to obtain in-depth feedback on the potential advantages and limitations of NMS learning through avatar control in social scenarios, as well as mechanism of collaborative avatar control. Design probes, such as visual sketches or mockups, are intended to stimulate reflective inquiry and ideation about technology design [37, 38]. This method was employed to gather insights from key stakeholders, including hearing parents, ASL teachers of hearing adults, and educators for DHH children, regarding how elements of the avatar-based social game may benefit NMS learning in a playful and family-centered way. Furthermore, the study adopted the technology probe method, allowing participants to experience a working prototype that supports two persons to collaboratively control an avatar for ASL signing. This allows researchers to observe user interactions and facilitate discussion on future technologies that address user needs [50, 51]. This is especially important to obtain reliable feedback, as the collaborative experience may be difficult to imagine without direct interaction. Having users engage with collaborative avatar control that resembles real-life use may prompt comprehensive reflection on advantages, concerns, triangulation of insights, and envisioning future improvements.

4.1 Interview Study

We conducted semi-structured interviews with hearing parents, ASL teachers, and SLPs to investigate NMS teaching and learning practices and feedback on CoSignPlay's design, including the overall game concept, and the one-player and two-player modes of human-controlled avatar signing. Due to limited access to direct input from young DHH children, parents were engaged as proxies to offer insights and feedback.

4.1.1 Participants. We recruited six hearing parents of DHH children aged 6 months to 5 years (PP1 - PP6) (Table. 1), six ASL teachers from adult ASL programs (TP1 - TP6) and two SLPs from early childhood education programs who work with DHH children and hearing families (SP1 - SP2) (Table. 2). We recruited the participants through study flyers shared with US-based ASL departments, schools for the Deaf, parent groups of DHH children on social media, and through snowball sampling. Interviews were conducted via

Zoom and lasted one to two hours. Participants received compensation of $30/hour. All participants consented to the information sheet before the study and this study was approved by the Institutional Review Board of the researchers' university.

4.1.2 Interview Study Procedure. A semi-structured interview was conducted to explore the opportunities and challenges in current ASL learning and teaching practices faced by hearing parents and ASL educators, as well as their feedback on CoSignPlay's potential to support NMS learning in family settings. Participants filled out the demographic questionnaire before the study. The interview includes three parts:

Part 1: General discussion. Participants reflected on their experiences teaching or learning NMS, what they found effective, and the challenges they encountered. They shared insights into collaborative and playful ASL learning approaches, particularly for NMS, shared relevant activities, and evaluated both existing opportunities and the potential benefits and limitations of the technology tools they had used to support ASL learning.

Part 2: Design probe interview. Participants first watched a demo video of CoSignPlay's single-player mode in the Yes/No questions scenario, showing both correct and incorrect signing paths. They could ask any questions or request replays. They then watched three more demo videos illustrating other scenarios: negation, degree, and lexical. Afterward, participants evaluated the game design and mechanics, including avatar mirroring, the provision of instant feedback, and undesired outcomes caused by incorrect signs. Educator participants discussed the appropriateness of the chosen NMS categories; parents and SLPs assessed their suitability for DHH children. Participants then viewed a two-player control demo and discussed their perspectives on single-player vs. two-player modes and the collaborative version's potential impact on learning. Parent and SLP participants further considered its suitability of this design for collaborative learning in families and suggested potential game scenarios and improvements for future design iterations.

Part 3: Technology probe interview. Participants interacted with the working prototype with a researcher to explore the core functionality of human-controlled avatar signing. We provided four sample videos produced by an ASL instructor, covering four categories of NMS: Yes/No questions, negation, degree, and lexical. The sample videos were played repeatedly until the participants felt ready. During the interactive section, one researcher counted down from three (using fingers for Deaf participants), then the participant and researcher collaboratively reproduced the ASL sentence from the sample video. Participants first controlled the MS while the researcher controlled the NMS, then switched roles and repeated the process. Through the hands-on interactions, participants explored the collaborative control concept. Researchers revisited the key questions discussed in Part 2 and gathered further feedback. Additional questions focused on the suggestions of this collaborative setup to enhance ASL acquisition among hearing parents and DHH children.

4.2 Data analysis

Interviews were video-recorded and transcribed anonymously by a third-party transcription service called Rev [100]. Transcription files were imported and managed using NVivo version 15 [73]. Inductive thematic analysis [16] was used to analyze the interview transcript. This method begins without predetermined frameworks, offering a 'starting point' for the flexible analysis of data and enabling themes to be constructed through concept synthesis [17]. Two researchers actively read through the transcripts and independently developed codes that related to the context of research questions. To ensure the validity of analysis, two researchers discussed the emerging codes and addressed discrepancies between codes. These codes were synthesized into themes based on conceptual similarities.

5 Results

5.1 RQ1: What are the opportunities and challenges for hearing parents to learn NMS in ASL?

5.1.1 Opportunities for hearing parents to learn NMS in ASL. We identified five main channels through which hearing parents have the opportunity to learn ASL. The first three perspectives reflect general ASL learning, while the last two are NMS specific.

Classroom-based learning. Two parent participants (PP1, PP5) reported attending in-person ASL classes, which they found helpful for foundational exposure to NMS. Educator participants echoed this, describing classroom techniques that support NMS learning, such as demonstrations and peer feedback in small group activities (TP1, TP2, TP4, TP5). As TP2 noted, *"Demonstrating and having them imitate is the best way."* TP4 shared that *"[Students] work with one another for facial expression and body language"*, and TP1 emphasized that such peer practice is more beneficial than learning alone.

Home-based learning opportunities. Home visits and early education programs can provide rich opportunities for families to learn ASL through daily routines. Five out of six parent participants (PP1, PP3–PP5, PP6) had participated in these forms of in-home instruction. Educator participants also recognized home-based learning as a valuable resource. *"An ASL specialist would go to the home and teach the parents and the child ASL at the same time using real-world experiences"* (TP3). These sessions focus on social communication skills, as SP2 explained, *"we're doing a lot of turn taking … getting them to just expand their sentences so it's not just one sign."*

Technology-based learning tools. Digital tools provide accessible ways to supplement ASL learning. Parent participants mentioned joining online ASL courses through platforms such as Zoom (PP1, PP4, PP6), Google meets (PP1), and Facebook (PP2). Educator participants utilize tools like GoReact (TP1) to offer personalized video feedback, and Marco Polo (SP1) to send signing demonstrations directly to families. Other apps and websites mentioned by participants include ASL Bloom (PP6), HandSpeak (TP4), Lifeprint (TP4), Lingvano (PP4), SigningsSavvy (TP4), and YouTube (PP2 - PP6).

Cultural immersion and community engagement. A few participants (TP5, PP3, PP4, SP1) suggested that engaging with Deaf community members is beneficial for their ASL learning, especially for learning NMS. SP1 shared that there are school program that *"connect [volunteers from the deaf community] with the [hearing]*

Table 1: Background information of parents that participated in the study

ID	Age	Gender	ASL Level	DHH Child's Age	Child's Hearing Loss Level
PP1	38	F	Intermediate	2y	Severe (71-90dB)
PP2	37	F	Intermediate	5y 8m	Profound (>90dB)
PP3	35	F	Survival	2y 10m	Moderately Severe (51-70dB)
PP4	28	F	Novice	8m	Mild (<30dB)
PP5	26	F	Novice	1y 8m	Moderately Severe (51-70dB)
PP6	34	F	Intermediate	2y 8m	Moderately Severe (51-70dB)

Table 2: Background information of educators who participated in the study

ID	Age	Gender	Hearing Status	Profession	Years of Teaching Experience
TP1	53	F	Deaf	Teacher	More than 5 years
TP2	54	M	Hard-of-hearing	Teacher	More than 5 years
TP3	57	F	Deaf	Teacher	More than 5 years
TP4	52	F	Hearing	Teacher	More than 5 years
TP5	37	F	Deaf	Teacher	More than 5 years
TP6	70	M	Deaf	Teacher	More than 5 years
SP1	52	F	Hearing	SLP	More than 5 years
SP2	26	F	Hearing	SLP	4 years

families and the kids." to provide opportunities for community engagement. As TP5 noted, seeing deaf people in natural conversation helps learners recognize *"the level of facial expression that's being used"*, which leads to *"less researvation on trying it on for themselves."* Such exposure helps hearing individuals gain a more comprehensive understanding of Deaf culture. Parent participants (PP3, PP4) also emphasized that interacting directly with Deaf individuals is essential for language development, describing it as *"the true only way to improve and nearly either forcing yourself."* (PP3).

Collaborative learning experiences. When discussing collaborative learning between hearing family members and DHH children, most participants (TP1, PP3 - PP6, SP1) reported having no such experience. Educator participants mentioned several teaching practices for collaborative learning NMS, such as the "Lost and Found" game, where *"[one student] hide[s] the keys ... [another student] ha[s] to look for that key. And if they're close [to the key], they will have this kind of facial expressions."* (TP2) Another example is visual gestural communication, which *"is heavily rely[ing] on gestures and facial expressions [for collaborative learning]."* (TP3) Parent participants (PP1, PP2) also described informal home practices that involved joint learning or use of ASL. For example, PP1 shared that their family engages in "voice off" hours to encourage the use of ASL at home. *"Our goal is to use as much sign language and gestures as we can to respond … even though we may not know all of the signs … we often resort to gestures, resort to facial expressions."*

5.1.2 *Challenges of NMS learning for novice learners.*

Cognitive Challenges.

- **Different modality from spoken language.** Many parent participants (PP1, PP3, PP5, PP6) found it difficult to shift from spoken language to a visual language, which poses a significant cognitive demand on them. *"The biggest challenge for me is the lack of overlap with the English spoken language."* (PP3) This difficulty is also highlighted by some educator participants (TP1, TP3). For example, TP3 noted that *"It's a different modality cognitively. [Because] they were born learning a spoken language, their brain becomes wired to [ASL]."*
- **Need to process and memorize multiple elements.** Another cognitive challenge is the need to memorize and produce both MS and NMS simultaneously, which can be overwhelming to novice learners. PP5 described this as "tricky", explaining, *"I'm learning the sign, but I'm also learning the facial expression that goes with the sign."* PP2 and PP6 also noted difficulties in remembering both the signs and their corresponding facial expressions. Some educator participants (TP2, TP4, TP5) confirmed this struggle, with TP5 emphasizing that *"ASL is a beautiful but also complex language because you have everything going on at once."*
- **Lack of grammar knowledge.** Some educator participants (TP2, TP3) identified that hearing learners often struggle with understanding the grammatical function of NMS. For example, the use of eyebrow position or mouth morphemes often carries specific grammatical meanings in ASL, but many hearing learners are unfamiliar with these elements. *"[NMS] is the grammar, but they don't understand how to use it"* (TP3).
- **Not realizing the importance of NMS.** Novice learners often fail to recognize the essential role of NMS in conveying meaning, focusing solely on the MS. TP2 shared, *"I've noticed in my experience teaching that a lot of students … don't realize that they need to also incorporate their facial expressions [when signing]."*

Cultural barrier. For many hearing learners, especially adults, using expressive facial expressions can be unnatural or even embarrassing. *"We don't use a lot of non-manuals when speaking … it can feel awkward or embarrassing"* (PP6). Several educator participants (TP4, TP5, SP1) noted that this discomfort often leads to learners minimizing their facial expressions, limiting communication effectiveness. This barrier can be even amplified by cultural norms. TP5 observed, "It's not typically a part of Asian culture to be super expressive on their face." Gender expectations can also play a role. *"Moms usually ... be doing their shifts and dads are a little more stiff and ... afraid to show that emotion."* (SP1).

Practical challenges. Parent participants (PP1, PP4) highlighted the difficulty of practicing ASL due to lack of accessible community or support in their surroundings. *"We do not have a solid deaf community for our child to be involved in, nor for us."* (PP1) Similarly, PP4 said, *"It is hard to practice when you have no one to practice with and no one to check that you're correct."* Educator participants (TP1, TP5) echoed this concern, emphasizing that consistent use is key for retention, yet opportunities for NMS-specific practice are limited. *"Classes in theory emphasize non-manual markers, but they don't often do activities to practice it."* (TP5)

5.2 RQ2. What are the affordances and limitations of the design concept of human-controlled avatar signing game for NMS learning?

5.2.1 Affordances of single user avatar-based learning for NMS.

Self-learning and self-assessment. Most participants (TP1 - TP4, PP1, PP3, PP4) shared that using 3D avatars can enhance self-learning and self-assessment, as learners can visually mirror their movements and recognize errors. *"They see the avatar doing what they're doing, they're quicker to recognize their own mistakes and correct it."* (TP1). TP2 and TP3 also saw it as a supplemental tool to provide practice opportunities when learners are alone. *"You can use it like homework at home or supplemental teaching … I think [that] help[s] them practice on their own"* (TP2).

Reduce self-awareness and embarrassment. The avatar-based game design offers learners a sense of privacy, reducing the anxiety often associated with practicing ASL in front of others. Several participants (TP1, TP2, TP5) emphasized that it could help learners who feel embarrassed about making mistakes in front of others. *"For people who … feel embarrassed to practice in real life with other people and they don't want to make mistakes, this is a place for them to get that feedback"* (TP5). TP1 also highlighted that seeing avatar signing can reduce anxiety, as some learners *"feel better not seeing their own face, [but] seeing the avatar make the mistakes"* (TP1).

Increase child engagement. Some participants (SP1, PP1, PP4) noted that avatar-based interaction can increase children's engagement by offering a sense of control and fun. Being able to make the avatar move through their own actions was seen as particularly motivating. *"My older son … would probably be able to pick up on them and engage in this … Being able to control the avatar would be exciting for him."* (PP1). PP4 imagined that even children who are not initially interested in learning ASL might be drawn in by the game aspect: *"I can see other kids wanting to make the avatar move … I could see it as more of a game."*

5.2.2 Limitations of single user avatar-based learning for NMS.

Naturalness of the avatar movement. Most participants (TP1 - TP3, TP5, PP3 - PP5) expressed concerns about the avatar's naturalness. TP1 emphasized the importance of clear facial expressions, fingerspelling, and nuanced mouth movements to make it *"more lifelike, more natural, like a real person."* Several participants also questioned the tracking system's accuracy. As TP5 noted, *"There are thousands and thousands ... of non-manual markers,"* making the task of accurate recognition especially complex. TP2 added, *"the [tracking system] need[s] to be very sensitive to the movement."* PP3 questioned whether subtle expressions in children would be detectable, asking, *"Would their actions be noticeable enough? Would my little toe-head blonde Dutch child's eyebrows be recognizable to a camera?"*

5.2.3 Overall feedback and suggestions for future design.

Overall feedback All participants, except for PP3, appreciated the design concept in which incorrect signs lead to undesired outcomes. PP3, however, felt the game concept was *"slightly generalized. I think that from my understanding and learning and exposure to the Deaf culture, there is some forgiveness—that any effort to use ASL from a person who is hearing is appreciated ... If a person only was learning from these games, I think they may have hesitation or fear to continue to use their ASL knowledge when they encountered somebody who is Deaf or hard of hearing."* Meanwhile, all educator participants (TP1–TP6, SP1, SP2) agreed that the categories of NMS we selected were appropriate.

Suggestions for future design First, participants gave several suggestions regarding avatar design. They (TP4, PP4, SP1, SP2) showed interest in avatar customization to help people feel more connected and bring extra entertainment. SP2 noted that, *"if there are ways to change what [avatars] look like, it'd be fun [for kids]."* Also, having the options to show multiple angles of avatars (PP4 - PP6) and to enlarge the size of avatar (PP1) would be beneficial *"for someone ... that wanted to make sure that [they] were signing it correctly."* (PP5) Second, all participants suggested relevant contexts for the game, including home life (e.g., washing dishes) (TP1, TP2, TP5, PP1, PP2, PP6), school (e.g., learning U.S history) (TP4, TP5, PP1, PP2, PP3, PP6), recreation (e.g., playgrounds) (TP1 - TP6, PP1, PP3, PP4, SP1, SP2), and emergency situations (e.g., hospital) (TP1, TP5, SP2). These insights reflect that participants see the game not only as a tool for enhancing language acquisition but also as a platform for developing practical, academic, and social skills. Last, participants (PP1, PP3 - PP6, SP1, SP2) suggested that this avatar-based learning technology is more suitable for older children. They cited several concerns regarding younger children, including that they *"cannot read"* (PP6, SP2), have *"limited screen time"* (SP1, PP1), find it *"hard to [sit] at a game and really [pay] attention"* (SP2), and often have *"limited language skills"* (SP2).

5.3 RQ3: What are the affordances and limitations of the design concept of collaboratively-controlled avatar signing for NMS learning?

5.3.1 *Affordances.*

Social benefits.

- **Family-centered learning.** Most parent participants (PP1 - PP3, PP4, PP6) emphasized that the collaborative gameplay may foster stronger family bonds by providing opportunities for joint learning. Rather than replacing parents' role in language learning, *"it required the parents to still be able to build that bond with their child … so much communication that could go on"* (PP1). The design can further include other hearing family members like siblings or relatives, making the DHH child feel less excluded from the family, as *"this would kind of help bridge the family members together"* (PP2). SP1 also pointed out the flexibility of remote participation. *"You don't have to be two parents in a home to do it. It could be a parent here and a grandmother in California."*
- **Reduce self-awareness and embarrassment.** Multiple participants (PP1, PP3, SP1) highlighted that collaborative play in a family setting reduces the level of embarrassment when making exaggerated facial expressions. Parents are typically more comfortable being silly with their children than with peers or coworkers. *"Parents … are a little bit more willing to make themselves look like idiots in front of their children"* (PP3). The playful nature of the game also encourages them to be more expressive. *"Just because it makes learning fun … makes it a little more comfortable to be funny with your facial expressions."* (SP1).
- **Increase learning engagement.** The collaborative design encourages active participation and sustained motivation. TP6 noted that the presence of peer pressure can positively impact performance. *"They feel that peer pressure … their team is relying on them … it is a form of peer pressure when they work collaboratively."* PP1 and PP2 also noted collaborative learning boosts engagement. *"Anytime you're in a social situation where you're both striving to reach for the same goal … you're both going to keep building on each other."* (PP1).
- **Alignment with Deaf culture.** During the discussion, TP5 and SP1 noted that the collaborative approach in the game resembles activities commonly found in Deaf culture. TP5 shared that, in the Deaf community, co-signing performances are often a source of entertainment and collective enjoyment: *"It's always hilarious to see someone sign and then someone else try to watch the signs and figure out the facials at the same exact time."* Additionally, SP1 mentioned another group activity known as the elephant game. *"The deaf people all stand in a circle and there's a person in the middle. They spin and point at someone ... the person pointed at has to do the trunk, while the people on either side do the ears. If you're not fast enough, then you go in the middle."* However, both participants noted that it is a culturally Deaf-centered activity, typically passed down through practice rather than written documentation.

Cognitive benefits.

- **Peer feedback.** Working collaboratively enables learners to observe and give feedback to each other in real time. Parent participants (PP2 - PP4) noted that players can coach each other during or after gameplay, reinforcing the learning even beyond the game itself. As PP2 described, *"Where one may be weak, the other can help strengthen their learning."* Educator participants (TP3, TP4) also valued peer feedback as an effective way of learning, mentioning players can identify mistakes and offer immediate feedback. *"You can see what's missing … and you can give one another feedback."* (TP4).
- **Potentially reduce cognitive load.** Many parent participants (PP1, PP3 - PP5) appreciate being able to focus on either MS or NMS at a time. *"It gives me time to figure out the facial expression I should use when doing the sign."* (PP5). They noted that it might be easier to integrate the other component after they feel confident at it. Some educator participants (TP1, TP4, SP1) similarly found that by learning each component separately before putting them together can be less overwhelming to beginners. SP1 shared a similar method that is implemented in practice. *"I actually have them practice the body and facial expressions without the signs for that exact reason … because it is hard to do two things at the same time."*
- **Address the importance of NMS.** The division of MS and NMS also emphasized the importance of NMS. PP6 explained that *"I don't pick up on the non manuals as much in other videos like my apps or even on YouTube … But the benefit of that tracking is just bringing awareness to it."* TP4 also echoed this affordance, mentioning *"hearing learners … struggle with putting those components together … [Practicing separately] helps to emphasize the importance of the non-manual signals."*

5.3.2 *Limitations and suggestions.*

Concerns about dividing control of MS and NMS.

- **Holistic nature of NMS.** Several educator participants (TP1, TP3, TP5, TP6) expressed concern that splitting control of MS and NMS could compromise the holistic nature of ASL. They emphasized that learning them separately may lead to unnatural timing and disconnection between signs and expressions. *"When it's time for them to actually incorporate the facial expressions, it's way off from what they've actually signed."* (TP5). TP1 also stressed that not learning both simultaneously *"makes it more challenging to have that fluidity."* PP5 suggested that children might find it confusing to focus on only one component, because *"they're just trying to figure out a way to communicate ... not worried about how their eyes or eyebrows look."* After trying the collaborative prototype, some participants (TP1, TP5, PP6) shared that their NMS naturally accompanied MS, *"It's too hard to sign without facial expressions."* (TP1). However, once learning that the system tracks only one channel, but allows both NMS and MS, participants felt more positive about the collaborative signing approach.
- **Difficulty in synchronization.** Another common concern is the coordination between two players (TP5, TP6, SP1, SP2,

PP6). TP5 noted that differences in signing speed and style could cause constant mismatch, mentioning that *"you're always going to have one beat off."* This difficulty in synchronizing requires players to spend more time practicing to coordinate, which may *"disinterest people because they have to practice so much before [getting it perfectly]."* From the learner perspective, PP6 shared that mismatched skill levels could make collaboration difficult and reduce immersion. *"If [you] aren't at the same signing level as your partner, it might be more complicated to collaborate in that way."* (PP6).

5.3.3 Additional feedback for future design.

Emphasize the holistic nature of MS and NMS while incorporating benefits of collaborative learning.

- **Incorporate both individual and collaborative avatar control mode.** Participants (TP4, PP5) suggested offering flexibility between individual and collaborative modes to support learners at different proficiency levels. Novice learners can better understand the holistic nature of ASL by first working individually, and then switch to collaborative mode for more in-depth learning. *"Working individually will help you understand the concept ... and then ... work with a partner to do a little bit more."* (TP4). Similarly, PP5 appreciated the option of collaborative play but emphasized that *"someone who's been signing for 34 years ... might not like that"*, indicating that experienced signers may prefer more integrated control.
- **Support role switching between MS and NMS.** To retain the benefits of decomposition without compromising holistic understanding, several participants (TP3, TP4, PP3, PP4) supported the idea of allowing players to switch roles. This enables both learners to practice the full spectrum of the language. *"I think as long as both players had an opportunity to do both roles, it would be beneficial for both learners."* (PP3). TP4 highlighted how role-switching can help learners "mesh the two" over time. PP4 added that being able to *"focus on one and ... switch in between gives you better practice"*, reinforcing the idea that alternation can support deeper learning and understanding.

Facilitate synchronization.

- **Introduce visual cues.** Adding visual aids in the user interface can help players better synchronize their signing during collaborative tasks. SP1 expected the collaboration to be difficult but found it manageable with the auditory countdown: *"I thought it would be much harder. I think counting down really helped so we're starting at the same time."* Similarly, SP2 suggested incorporating a visual countdown on the screen, noting that *"having the visual for 3, 2, 1 we're going is good"*, as it allows participants to better anticipate when to begin.
- **Introduce easy-to-hard synchronization level.** To manage cognitive load and support progressive learning, participants (TP1, TP3) recommended a leveled system that gradually increases the complexity. For example, early stages could focus on simple NMS like raised eyebrows in Yes/No questions, gradually progressing to more complex expressions to build coordination and reduce frustration. SP2 found this approach appealing, sharing that *"that would be really fun and motivating for the kids … they can see how far they get on the levels."*

Introduce competitive mechanisms. Another commonly mentioned idea is the integration of a competitive element, such as a scoring system to reflect individual performance (TP3, TP5, PP1, PP5). This can further motivate players to improve their skills. *"There's more motivation about who's going to get the points ... and that way there's more of a competition factor to it."* (TP3). Parents in particular noted that such mechanics could increase children's engagement. *"It's going to be engaging for the child to want to compete and do better. They're going to strive for perfection hopefully"* (PP1). Beyond formal mechanics, PP2 noted that a competitive spirit may naturally emerge during collaboration, as players compare performance and support each other's learning.

6 Discussion

Learning is a social endeavor. Feedback from the this study's stakeholders emphasizes the multi-faceted role of social interactions in ASL learning, from ASL modeling by ASL teachers and peer collaboration in ASL classrooms, to observation and interaction with members from the Deaf community. Despite these opportunities, hearing family members often face limited access to ASL classes and Deaf mentors due to time, cost, and availability of resources (see the latest survey [70]). Meanwhile, increasing attention to family-centered early intervention for hearing families with DHH children [49, 81] suggests a critical, yet under-supported resource for ASL learning in family environments. Through the design and technology probe with the CoSignPlay avatar-based collaborative game, we discovered a variety of social, cultural, and motivational benefits for ASL learning, especially NMS, by utilizing playful social interaction among hearing family members and DHH children. This section reflects on our findings and discusses key design implications and future directions in three aspects: (1) family-centered learning of NMS in ASL, (2) balancing holistic signing with cognitive scaffolding for novice learners, and (3) bridging ASL learning with the Deaf culture and community.

6.1 Family-centered learning of NMS in ASL

The idea of collaborative ASL learning involving all family members received positive feedback unanimously among participants, reflecting feelings of disconnection like the "dinner table syndrome". The three key benefits are:

6.1.1 Bonding between family members.

Parent participants thought that collaborative ASL learning may not only support bonding with their DHH children, but also with hearing siblings and other family members - potentially "helps bridge the family members together" (PP2). This might be especially beneficial for hearing fathers, who often fall behind their parenting partners in ASL fluency [124], and for remote family members, as SP1 noted. While these reflections are anecdotal, they resonate with previous research on family-centered learning [20, 85, 90, 113], showing that family involvement enhances communication and strengthens family bonds.

6.1.2 Reducing feelings of embarrassment. The discomfort or awkwardness revealed by several participants aligns with prior studies, due to cultural norms and gender backgrounds [41, 78, 125]. Participants' feedback shows that the avatar-based collaborative learning approach may help reduce these feelings. First, parents are often more comfortable acting playfully with their children. Second, practicing through an avatar may reduce embarrassment for hearing individuals compared to practicing in front of others. This aligns with previous findings that avatars lower learners' affective filter and anxiety by acting as a "shield", reducing concerns about being seen or judged [23, 57, 114, 119]. This approach may be particularly helpful for those whose cultural or gender norms suppress facial expressions in communication.

6.1.3 Promoting motivation and engagement. Participants noted that controlling the avatar could be particularly motivating for children, offering a sense of control and fun [4, 97, 101]. Additionally, collaborative avatar control can introduce peer feedback and peer pressure, both valuable in scaffolding learning [72, 82]. This approach offers flexible learning opportunities, especially for members of hearing families with DHH children whose ASL proficiency varies due to ASL learning opportunities, age, and first- vs second-language learners. Observing and interacting with peers allows students to reflect on their own work in relation to others', enhancing metacognitive awareness, communication, motivation, and learning outcomes [56, 67, 115]. Social constructivism and sociocultural theory similarly emphasize that learners co-construct knowledge through interactions with more knowledgeable individuals [121]. This collaborative learning approach is thus particularly beneficial for DHH children and hearing family members, as both parent and educator participants shared that DHH children often surpass their hearing parents' in ASL, echoing prior literature [107].

6.2 Balance between holistic signing and cognitive scaffolding for novice learners

Some participants felt that the collaborative approach helped reduce cognitive load by allowing learners to focus on one component at a time. Cognitive load theory, which emphasizes enhancing learning by optimizing cognitive processing and reducing mental overload [112], and empirical studies demonstrating that collaboration allows learners to offload parts of a task to each other [32, 60], together provide a strong foundation for the two-player signing approach. However, some participants expressed concern that this division might compromise the holistic nature of signing, given the simultaneous and integrated relationship between MS and NMS in conveying meaning [79, 120]. Once clarified that players can produce both MS and NMS, with the system selectively mirroring each, participants' concerns were reduced. Therefore, it's important to incorporate both holistic signing experience, and seek cognitive scaffolding for novice learners who may benefit from offloading cognitive demands.

6.3 Bridging ASL learning with the deaf culture and community

Group narrative, where multiple people collaboratively perform a story using sign language, often through exaggerated performance, is a common activity among DHH children, Deaf schools, and social gatherings of the Deaf community [102]. However, this practice remains largely unknown and undocumented outside the Deaf community. To our knowledge, CoSignPlay is the first design concept that adopts a unique form of group narrative, where two people contribute NMS and MS respectively. There is yet a rich but untapped set of folk and social activities deeply rooted in Deaf culture, such as other group narratives and the elephant game, which may inspire novel culturally grounded learning tools, particularly for hearing family members of DHH children. Furthermore, learning experiences like CoSignPlay that adopt group activities rooted in the Deaf culture may help bridge these families with the Deaf community. As participants commented, hearing families are often remote from the Deaf community, which is considered a critical cultural capital for DHH children [43, 71]. Bridging ASL learning with the Deaf culture and communities requires joint efforts from researchers, educators, and members of both Deaf and hearing communities. This direction may profoundly impact the positive development of DHH children, aligning with the vision of the Deaf Mentor program for connecting DHH children with Deaf individuals [40].

6.4 Design implications for future NMS learning technologies

6.4.1 Collaborative control of avatar signing.

- **Synchronization** Although participants appreciated the reduced cognitive load enabled by collaboration, half of the educator participants (4/8) expressed concerns about the difficulty of synchronizing their assigned signs with their partners'. This coordination could require additional effort to ensure accurate avatar signing, as Joint Action Theory highlights the complexity of coordinating shared tasks with others [105]. Future designs could include visual cues (e.g., countdowns, guided animations) to support smoother coordination. Additionally, as SP2 suggested, future systems could incorporate varying levels of synchronization difficulty. For example, Yes/No questions involve minimal synchronization, typically requiring a single NMS (e.g., raised eyebrows), while degree-based sentences (e.g., "large or larger pizza?") involve more complex timing with multiple NMS. This tiered structure aligns with studies showing that progressive game-based learning improves learning outcomes, motivation, problem-solving, and self-efficacy [130].
- **Naturalness of avatar movement** Participants highlighted the importance of natural avatar movements via accurate tracking. This is critical to realize authentic and effective MS and NMS in ASL as a human signer would do. This aligns with Wolfe et al.'s [128] in-depth analysis of avatar display features, which emphasizes that the effectiveness of sign language avatars depends on movement accuracy and naturalness, ensuring that the signing is acceptable and easily understood.

6.4.2 Customization to fit learners' needs.

- **Single-player vs. two-player** The different attitudes toward collaborative learning suggest the need for a human-in-the-loop approach [83], allowing families and other stakeholders (e.g., educators) to customize the technology to their needs. For instance, educators may prioritize holistic ASL learning and adherence to linguistic standards, favoring single-player mode. In contrast, parents may prioritize building relationships with their child through peer interaction and value the distribution of cognitive demands [70, 112], making two-player learning more preferable.
- **Collaborative vs. competitive** Although collaboration can offer benefits such as increased engagement and knowledge co-construction [7, 59, 64, 110, 116], many parent participants shared that their children prefer competition, which can motivate them to perform better and strive for perfection. Xu et al. [129] found that game-based competition has significant effects on online learning performance in knowledge mastery, application, and innovation. Future designs could incorporate both collaborative and competitive modes. For example, in the competitive mode, players who sign incorrectly would lose points, while signing correctly would earn points. Despite the individual scoring, both players still need to collaborate to proceed with the game.
- **Avatar appearance** Participants expressed interest in avatar customization, noting that it could strengthen the sense of connection during learning. Supported by findings, personalized avatars enhance identification, embodiment, agency [21, 101, 122], and boost engagement and motivation in learning [87]. Participants also recommended that users be allowed to change avatar size and viewing angles. This helps to improve visual clarity, especially for observing subtle NMS often missed in typical 2D or limited 3D ASL learning tools.

6.4.3 *Special design considerations for young and DHH children.*

- **Minimize text-based instructions** Participants noted that young children often cannot read and have limited language skills. Future technologies should offer visual prompts to support pre-readers. Since the game is designed for collaboration between hearing family members and DHH children, adding auditory prompts can guide hearing users and help sustain focus and communication clarity.
- **Lower-tech options** Participants noted a desire to limit screen time and observed their children's limited attention spans for ASL practice via technology. We recommend future tools provide brief, engaging sessions with physical interactivity to match young children's developmental needs and screen-time constraints.

6.5 Limitation and Future Study

As an exploratory investigation, this study has several limitations that open avenues for future research and improvement. First, this study included only two SLPs, limiting the diversity of professional perspectives on family-centered ASL learning. We did not interview DHH children due to their young age (6 months to 5 years), relying instead on parent proxies—an approach that may introduce bias related to age, hearing status, and learning abilities. Additionally, all parent participants were female. While this aligns with prior findings that mothers are often more involved in intervention [132], it may narrow the range of viewpoints. These limitations suggest our findings should be considered preliminary. Future studies should include more SLPs, DHH children and male caregivers to capture broader insights and better assess usability across diverse users.

Second, due to limited video recording resolution, we didn't include observational insights of participants' signing performance. To obtain richer behavioral insights, future studies should ensure high-quality video recordings that allow for performance-based analysis of signing interactions.

Third, although the research team includes both DHH and hearing researchers, it was a hearing researcher who worked directly with participants using the working prototype during the interview. Since this study centers on collaborative learning among hearing family members and DHH children, the hearing status of the facilitator may influence the interactions. Future research should consider involving both DHH and hearing facilitators and explore adaptive designs that accommodate family members with diverse communication and ability needs.

7 Conclusion

We proposed CoSignPlay, an ASL learning game that focuses on NMS and integrates an avatar-based collaborative learning experience, to better understand the design space for learning technologies supporting ASL acquisition. We found that participants have access to several opportunities to learn NMS However, they often face challenges in acquiring and applying NMS due to cultural barrier, cognitive and practical challenges. Participants expressed mixed attitudes toward the concept of an avatar-based collaborative learning game for ASL. They appreciated the social and cognitive benefits while expressed concerns about dividing control of MS and NMS. Future research could address the limitations identified in this study and incorporate the design recommendations proposed.

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