SignIt! AN ANDROID GAME FOR SIGN BILINGUAL PLAY THAT COLLECTS LABELLED SIGN LANGUAGE DATA

Roshni Poddar[1,*], Pradyumna YM[1,*], Divya Prabha Jayakumar[1], Tarini Naik[1], Punyat Tripathi[2], Nabeel TP[2], Hemanth Reddy Yeddula[2], Pratyush Kumar[1], Mohit Jain[1], Manohar Swaminathan[1]
[1]Microsoft Research, India, [2]National Institute of Speech and Hearing, India

* Both authors contributed equally to this work.

Abstract – The Deaf or Hard-of-Hearing (DHH) community constitutes over 430 million people globally, with about 70 million of them using sign language as their primary means of communication. India has around 63 million DHH individuals. The DHH community in India faces several challenges, particularly in learning sign language and English, due to delayed diagnosis, stigma, oralism, and a diversity of languages. Digital games for spoken and sign language learning have gained popularity due to their advantages over traditional language learning methods, such as enhanced engagement and socialization, driving increased research and adoption over traditional methods. Moreover, the development of robust machine learning models for sign language recognition, which could significantly improve access for signers, is currently impeded by the scarcity of labelled sign language data. To address these challenges, we collaborated with NISH, an academic institution for the DHH community and developed *SignIt!*, an accessible and inclusive quiz platform that facilitates the learning of English and Indian Sign Language (ISL) with a secondary goal of data collection. To assess the game's usability, we conducted a study with 20 members of the DHH community, followed by interviewing 15 participants. Overall, our participants answered 2160 quiz questions and created 210 questions. The quiz creation resulted in the collection of three hours of labelled real-world sign language data. The interviews revealed novel insights, such as a preference for playing competitively with friends, empowerment by their agency to be content creators, and early signs of learning English, sign language, and quiz content by playing and creating quizzes. We plan to open-source and release *SignIt!* to increase its adoption among diverse DHH communities.

Keywords – Creation, deaf, game, hard of hearing, learning, multiple-choice question

1. INTRODUCTION

The Deaf or Hard-of-Hearing (DHH) community constitutes over 5%, or 430 million people, of the global population [1]. Due to the inaccessible nature of their environments, this community faces challenges in various facets of their everyday lives, including communication, learning, and play [2, 3]. In particular, learning sign language has been found to be challenging for DHH children, as more than 90% of deaf children are born to hearing parents with no/minimal levels of sign language proficiency [4], thus lacking access to language learning at home from parents.

India is home to about 15% of the world's DHH population [5]. The DHH community in India faces several additional challenges in learning sign language and English due to various social and cultural factors. For instance, due to the overburdened healthcare system, the average age of diagnosing hearing impairments in India is 24.3 months, and for early intervention is 33.4 months [6]. This delayed diagnosis results in delayed language acquisition, which often leads to poor academic performance and school dropouts [7, 8]. Moreover, DHH children lack access to language learning at home and at school due to the stigma associated with deafness, the exclusive oralism in integrated schools, and the diversity of spoken languages and cultures resulting in a fragmented DHH population.

For more than 5 million DHH people in India, there are only 387 special schools [9]. This is despite India being a signatory to the United Nation's CRPD (Convention on the Rights of Persons with Disabilities) [10], which recognizes inclusive education as a right of children. Even in these Indian schools for the Deaf, access to qualified sign language teachers is a challenge, as there are less than 500 certified ISL (Indian Sign Language) interpreters in India. Recent advances in machine learning research could help overcome the shortage of human resources by enabling applications such as personal digital assistants that respond to signed commands, automatic sign language transcription services, and automatic translation of a sign language to spoken language and vice versa [11]. However, the development of robust machine learning models is hindered by the lack of labelled sign language data recorded in real-world settings [12].

To address these challenges, our group at Microsoft Research India initiated a research collaboration with the National Institute of Speech and Hearing (NISH) (about 4 years ago). NISH is an academic institution working on the identification, intervention, rehabilitation and education of individuals with (hearing) disabilities. They provide bilingual education to their DHH students, an approach that uses both the sign language of the deaf com-

© International Telecommunication Union, 2023
Some rights reserved. This work is available under the CC BY-NC-ND 3.0 IGO license: https://creativecommons.org/licenses/by-nc-nd/3.0/igo/.
More information regarding the license and suggested citation, additional permissions and disclaimers is available at:
https://www.itu.int/en/journal/j-fet/Pages/default.aspx

munity and the written/spoken language of the hearing community, recognized as one of the best ways to teach DHH children [13, 14, 15]. As part of this collaboration, two Deaf teachers of NISH (one teaching ISL, and another working with early-stage ISL intervention) visited Microsoft Research India for 6 weeks, and 6 DHH students from NISH interned with us (three of them are co-authors of this research paper).

Our collaboration commenced with the goal of gaining a deeper understanding of the Indian DHH community in terms of the existing education system and its barriers, communication challenges they encounter and how they manage these challenges, and the technologies they use both for education and in their personal lives. The hearing authors also set out to learn ISL and to understand Deaf culture through frequent interactions with native signers. We utilized interpreters for extended conversations and employed available tools such as Whatsapp, captions, and finger spelling for informal communication. Our in-person collaboration was interrupted by the pandemic, after which we continued our engagement online. We explored and evaluated games played by the DHH community, games designed for sign language learning in the literature, and brainstormed how the Ludic Design for Accessibility methodology could be leveraged to create games that facilitate language learning. This methodology involves creating games that impart specific skills and benefits to the players through extended play [16, 17, 18]. Our long-term collaboration has led to the following three research contributions (A preliminary version of the work reported here appeared in [19]):

(1) SignIt!, an Android game developed using the ludic design methodology in collaboration with the DHH community. It enables individuals to play sign language-based quizzes either solo or with others, and to create their own quizzes using the built-in video recording feature. Each quiz consists of three or more multiple-choice questions in sign language, with hints containing the English translation of each ISL question and option. Players can alternate between sign language and English while playing, which supports them in learning new words and phrases in both languages. SignIt! is designed to be agnostic to the sign language and the spoken language and is being open-sourced for adoption by diverse DHH communities.

(2) We present the findings from our mixed-method user study with 20 DHH participants, which was conducted to explore the usability, game play behaviour, social interaction, and learning aspects of *SignIt!*. Overall our participants answered 1769 multiple-choice questions playing solo and 391 questions while playing with others, and created 82 quizzes containing 210 questions. From the semi-structured interviews with 15 participants, we gained novel insights. We observed early signs of learning English, sign language, and quiz content in the process of playing and creating quizzes. Despite only 18.1% of questions being played in social mode, our participants preferred playing and competing with others, but they struggled to find a suitable time to play together. Finally, our participants felt empowered with their agency to be content creators and identified venues to promote their created quizzes.

(3) We provide early indications of the potential for labelled sign language data collection resulting from participants creating quizzes on *SignIt!*. The quiz creation resulted in the collection of 2,931 isolated and continuous sign language videos lasting a total duration of 3 hours and 12 minutes. The isolated sign language dataset consisted of 1573 videos, with 751 unique words such that 95 words were signed by three or more users. The continuous sign language dataset included 1358 videos of sentences, with a vocabulary of 1948 words such that 390 words were signed by three or more users.

2. RELATED WORK

In this section, we explore prior work on sign language learning games and gamified approaches for sign language data collection.

2.1 Sign language learning games

Current estimates show that more than 91% of American children aged 8-18 years play almost 110 minutes of (smartphone) video games daily [20]. In spite of the ill effects of excessive gaming, digital games have immersive properties, demand active participation, challenges an individual to develop new skills, and provide emotional and social support, which has potential to benefit the learning experience [21, 22]. Due to these reasons, games have been developed for a variety of sign languages across the world, including American SL [23, 24], Australian SL [25], Arabic SL [26], Chinese SL [27], Brazilian SL [28], and Indian SL [29]. Based on the interaction mechanism, these sign language games can be divided into two broad categories: (1) learn-by-view: wherein the game shows signing videos/avatars to the player to help them learn new signs [26, 30, 25, 28], and (2) learn-by-practice: wherein apart from the signing videos/avatars, the game prompts the player to mimic signs with feedback to help them improve the correctness of their signing [23, 27, 24, 29].

Sign my World [25] is a learn-by-view Australian Sign Language game, to familiarize DHH children with commonly-used nouns and verb signs. The game interface has a 2D environment (e.g., a bedroom) containing various interactive objects. On clicking an object, it displays a zoomed image of the object and its name on a flash card, followed by a video of the sign for that object. This helps children to make associations between the object and the sign. On similar lines, Ada Runner [28] is a Brazilian Sign Language game about traffic education to teach children 28 basic traffic-related signs. Ada Runner was only evaluated by educators and there are no reported results of children using the game. Similar games are also available on Google Play and Apple App Store, such as ASL Bloom (American SL), Lingvano (British SL), and ISL Journey (Indian SL), offering a structured way

©International Telecommunication Union, 2023

to learn sign language from recorded videos. Although learn-by-view can help with learning sign recognition, it remains a challenge of such learners to sign themselves. Learn-by-practice games aim to address that key limitation.

CopyCat is a learn-by-practice American Sign Language (ASL) game, which uses gesture recognition to help DHH children practice ASL skills [23]. The game runs on a desktop computer, and uses a video camera and wrist mounted sensors to recognize a limited set of ASL phrases, focusing on the correct repetition of ASL phrases. Although it combines gameplay with sign language learning, the research work lacks evaluation with end users. SignFind [27] is a recent work that requires the players to wear wrist sensors and sign specific words in Chinese Sign Language to explore a virtual world. Similar to CopyCat, SignFind uses a gesture recognition software running on a desktop/laptop. The SignFind paper reports a pilot study with four children on a limited vocabulary. Virtual Sign [31] is a similar game that uses sensor gloves and Microsoft Kinect for learning Portuguese Sign Language. Although learn-by-practice games are better suited for learning, they require expensive hardware like gloves with embedded accelerometers [23], pinch gloves [24] and depth cameras [32] for tracking hand gestures, thus limiting their widespread adoption. Moreover, the desktop/laptop requirement restricts the gameplay to a non-mobile setting. Finally, current sign language recognition algorithms are limited to recognizing isolated words. Continuous sign language recognition focuses on recognizing phrases in sign language. It is ideal for teaching sign language; however, is an unsolved problem [33, 34].

2.2 Sign language data collection

To counter hardware requirements of learn-by-practice games, recent work has been exploring deep learning techniques for sign language recognition from video feeds recorded using off-the-shelf cameras [35, 36, 29]. There are various datasets proposed across the world to facilitate the training of these deep learning models. The ASLLVD dataset [37] is a widely researched collection of American Sign Language vocabulary, containing over 3,300 unique signs demonstrated by 1-6 native signers. However, only 48 of these signs have eight or more videos. All videos in the dataset have a uniform background to facilitate the segmentation of hands and face. The RWTH-Boston-50 [38] is a well-known dataset of 50 classes of American Sign Language vocabulary. RWTH-PHOENIX-Weather 2014 [39] is a dataset of German sign language, designed for continuous sign language recognition. It contains over a million frames and 1081 distinct words, recorded from a public television weather broadcast and performed by nine different signers. INCLUDE [35] is an open-source ISL dataset with 0.27 million frames, 4287 videos, and 263 word signs from 15 different word categories. These datasets are often recorded in lab settings with homogeneous signers. In an effort to collect real-world sign language data, accessibility researchers are exploring ways to gamify sign language data collection [11]. ASL Sea Battle is a sign language game designed to collect and label real-world sign language videos, while also providing fun and education to its users, taking away the drudgery of signing just for data collection. In this game, fluent ASL signers play a modified accessible version of the popular strategy game, Battleship, with hearing individuals on their smartphones. Their user study results suggest that ASL Sea Battle can be used to sustainably collect high-quality sign language video data, fetch accurate labels, and provide players with entertainment, education, and social connections. However, the current game is limited to signing isolated words. Although the paper mentions the possibility of using the game for learning American SL, that aspect has not been explored.

To summarize, existing sign language games have limitations, they typically focus on a limited vocabulary and lack multiplayer modes that foster social collaboration and competition. *SignIt!* overcomes these limitations by supporting multiplayer gameplay and encouraging user-generated content. Empowering players to create sign language content not only allows for diverse and engaging content for others, but also helps in collecting diverse isolated and continuous sign language data.

3. THE DESIGN OF *SIGNIT!*

During our brainstorming sessions with two teachers and six students from NISH, we came to know that they use Kahoot! (https://kahoot.com/) a popular online game-based learning platform with 1.6 billion users that engages students through interactive quizzes in a competitive and fun environment [40, 41] extensively in their classroom teaching. However, they struggle with Kahoot! as it primarily relies on text-based quizzes and lacks support for sign language quiz creation. Hence, we decided to co-design a sign language-based quiz platform, *SignIt!* with the goal of facilitating ISL and English learning in a fun and engaging manner. It enables players to play sign language-based quizzes in three modes—individual, group, and live. Moreover, it allows users to create their own quizzes using the built-in video recording feature. We paid attention to design visually appealing graphics and ensuring scalability to accommodate a large user base.

Below we describe the key elements of *SignIt!*.

3.1 Quiz play

The home screen of the *SignIt!* app provides a list of quizzes in different categories that the player can choose to play (Fig. 1a). On selecting a quiz, it shows relevant details of the quiz (like number of questions, quiz creator, and highest score) and provides options to play that quiz as a single player or with others in the 'Live' mode (Fig. 1b). On starting a quiz in any of the modes, the

 ©International Telecommunication Union, 2023

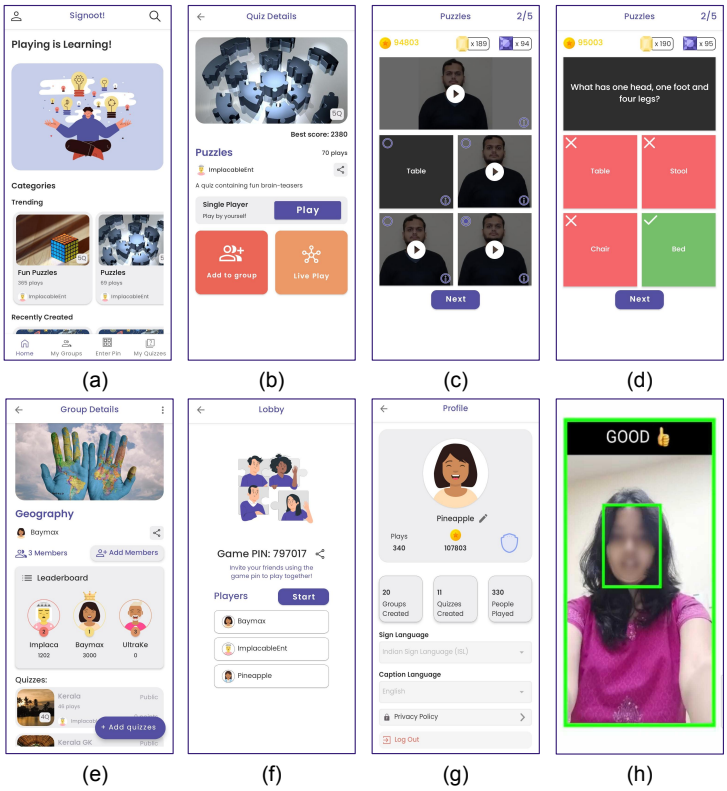

Fig. 1 – Screenshots of *SignIt!* (a) Home screen (b) Quiz details screen (c) Question screen (d) Answer analysis screen (e) Group details screen (f) Game lobby screen for live mode (g) User profile screen (h) Video recording interface

player lands on the question screen (Fig. 1c). This screen presents a question at the top along with two to four answer options below it. Both the question and options appear as sign language videos by default. The question video gets automatically played once the question screen loads. A user can play any video by tapping on the corresponding play button. Each option has three buttons: a radio button (on its top right) to select that option as an answer, a play button (on its centre), and a hint button (on its bottom left) to toggle the visibility of the corresponding English translation. The radio button and the hint button gets enabled only after watching the sign language video of that option once. After selecting an answer and clicking the 'Next' button, the answer screen (Fig. 1d) shows the question text and option texts, along with the correct option highlighted in green and the incorrect options highlighted in red. Clicking the 'Next' button on the answer screen takes the player to the score screen, which displays their answer's correctness, the points scored for the current question, and their total score for the quiz.

Each question is worth 1000 points. Players receive no points for answering a question incorrectly. If a player takes more than 20 seconds to answer a question, twice the number of extra seconds ($(timeTaken - 20) * 2$) are deducted from their score, up to a maximum deduction of 300 points. Using a hint incurs a penalty of 40 points; however, once a hint is used for any video, there is no further reduction for using it again. On finishing a quiz, the player is awarded virtual coins equivalent to their total score divided by 10, rounded to the nearest integer. The total coin count is visible in the top left corner of the question screen (Fig. 1c as 94803 coins). Apart from coins, players can also earn badges, e.g., '10 Correct Answers in a Row', 'Quiz created with 5+ questions'. In case the user is struggling to answer a question, *SignIt!* offers two power-ups, a golden power-up costing 500 coins that removes half of the incorrect options, and a purple power-up costing 1000 coins that removes all incorrect options. Both the power-ups are visible in the top right corner of the question screen (Fig. 1c as 189 available golden power-up and 94 available blue power-up).

Similar to Kahoot!, *SignIt!* supports three quiz play modes namely individual mode, group mode and live mode. These modes are detailed below:

Individual mode: Individual mode allows a player to play quizzes alone. A player can play the same quiz multiple times. While Kahoot! has a timer for each question in the individual mode, we decided not to impose a time limit as previous research revealed negative impacts of timers in Kahoot! [40], such as stress, reduced reflection, and rushed guesses. Additionally, we allow players to watch the sign language question/option video multiple times, considering different sign language proficiency levels.

©International Telecommunication Union, 2023

Group mode: In *SignIt!*, players can create groups and add other *SignIt!* players in their created groups. The group creator can add quizzes to their groups by clicking the 'Add to group' button in the quiz details screen (Fig. 1e). Groups serve as a way to bring players and quizzes together, adding an element of competition among players. Similar to the individual mode, group quizzes do not have a timer and can be played asynchronously. The group leaderboard showcases the cumulative points earned by each group member by playing quizzes shared in that group (Fig. 1e), fostering a competitive environment wherein players strive to top the leaderboard.

Live mode: Live mode allows multiple players to participate in a synchronous quiz. Players can start a Live mode game by selecting a quiz and choosing the 'Live mode' option. This creates a lobby with a randomly generated six-digit game PIN (Fig. 1f), which can be shared with other players to invite them to join the game. The quiz host (the player who started the quiz) also participates and the questions with options get displayed on all participating players' devices. To ensure a fair leaderboard across different questions, the same question appears on everyone's screen at the same time.

3.2 Create quiz

Apart from playing sign language quizzes, *SignIt!* enables players to create quizzes on their areas of interest and expertise, which they can then share with other *SignIt!* players. While Kahoot! allows players to add a video to the question, it doesn't provide a way to include videos for the answer options. In addition, the translated text of the question needs to be added as subtitles in the video. We believe that a sign language question with visible text has limited opportunities for learning sign language.

In *SignIt!*, players can create their own quizzes by adding the quiz name, quiz image (optional), quiz description (optional), associated tags (optional), signing language (ISL, ASL, etc.), caption text language, and a list of questions with multiple options. To obtain licensed cover images for quizzes, we utilize the Pixabay Image search API. In order to make a quiz public to all players on *SignIt!*, it must contain a minimum of three questions, with each question having two or more options. As a reward for creating a public quiz, the player earns 1000 coins multiplied by the number of questions in the quiz.

The create question screen has a similar layout as Fig. 1c with placeholders for the question and four options. The user needs to tap on each of these placeholders to add the video and the corresponding caption. To create a valid question, the user must add the question, at least two options, and mark the correct answer among the options. After recording the video for a question/option, the placeholder is replaced with the sign language video along with the upload status of the video and an option to edit it. From our DHH co-authors, we received feedback that creating questions is "*time-consuming*" and "*challenging*". To address this concern, we added a 'Find question' feature, which allows players to quickly select questions from OpenTriviaDB [42], an open-source trivia questions database. As the OpenTriviaDB has multiple-choice questions in text, the player still needs to add the corresponding sign language videos. However, on internal testing, we noticed that none of the DHH students from NISH utilized questions from OpenTriviaDB, mainly because the questions catered to a "*Western audience*". For instance, a typical question would be "*Who wrote the play 'Angels in America'?*". As a result, we developed our own repository of multiple-choice questions encompassing topics such as Bollywood, sports, and Indian politics, ensuring a more relevant and engaging experience for our players.

Recording videos: The video recording interface (Fig. 1h) provides players with feedback such as 'Move closer', 'Move left', and 'Multiple Faces' to ensure that they are positioned correctly in the video frame for optimal visibility of their upper body. The feedback guides the user until they are well-positioned, after which a three-second countdown starts and the recording begins. During recording, the top right corner of the screen displays the time elapsed since the recording started, and the bottom part shows a 'Stop Recording' button. The duration of question videos is limited to 30 seconds, while option videos are limited to 15 seconds. Either the user presses the stop recording button or when the maximum time limit is reached, the recording stops and the video is saved. The three DHH co-authors created 11 quizzes on topics such as riddles, computer science, Indian state, etc., to populate an initial set of quizzes for the participants to play on *SignIt!*.

3.3 User profile

The user profile screen (Fig. 1g) displays a variety of statistics, including the number of quizzes played and created, and the frequency of others playing their created quizzes. It also showcases earned badges and coins. The user can customize their profile avatar and username. It also allows players to choose their preferred sign language (ISL as the default) and caption language (English as the default). These preferences automatically filters the quizzes displayed on the home screen (Fig. 1a), accommodating various language preferences. The user profile captures the basic parameters needed to automatically customize the user experience based on the specifics of the user's accommodation needs. This is motivated by the ongoing efforts to standardize the profiles of users by organizations like the International Telecommunication Union[43] and the International Standards Organization. (See for example [44] [45] [46]).

3.4 Implementation details

The *SignIt!* game is an Android application developed in Kotlin, designed to be a production-grade system. The system architecture of *SignIt!* is illustrated in Fig. 2. Dur-

 ©International Telecommunication Union, 2023

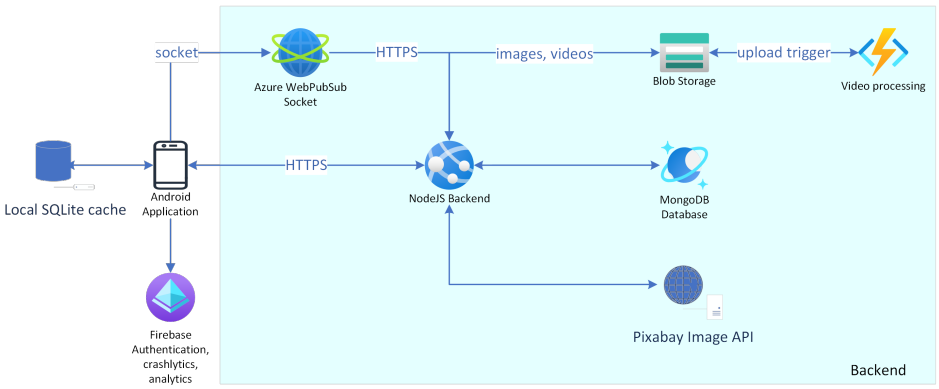

Fig. 2 – Architecture diagram for *SignIt!*. *SignIt!* app caches data locally on an SQLite database and authenticates users using Firebase. The app connects to the NodeJS backend through HTTPS. For live games, websocket connections are enabled through the Azure WebPubSub service to keep the backend stateless and scalable. Uploaded images and videos are stored in an Azure Blob container. Video uploads to the blob storage trigger an Azure function to centre crop and compress videos. Image search is enabled by the backend through a call to the Pixabay Image API.

ing development, one of the key challenges was managing latencies both during quiz creation and gameplay across various modes. To address this, videos recorded by players are initially stored locally on their devices and then securely uploaded to an Azure blob storage container using a background worker with HTTPS support. Uploaded videos automatically undergo compression and cropping through an Azure serverless function triggered by the blob storage. All video reads/writes are directed through the backend to ensure authorized access to the storage containers. For gameplay in the live mode, a shared state object representing the game state is maintained on the backend. Changes to the state are instantly communicated to relevant clients through web sockets to ensure minimal latencies. To maintain a stateless and scalable backend, web socket connections for live games are hosted on an Azure WebPubSub service, which in turn sends events to the backend via HTTPS. The backend, is implemented as a NodeJS application using the ExpressJS framework. It is hosted as a web application on Azure App Services with horizontal scaling enabled. User profile and quiz metadata is stored on a MongoDB database hosted on Azure CosmosDB. To ensure optimal performance under high loads, operations on the application results in point reads and writes on the database.

4. STUDY DESIGN

We conducted a mixed-method study with 20 members of the DHH community to explore the usability, gameplay behaviour, social interaction, and learning aspects of *SignIt!*. A mixed-method study, which integrates both qualitative and quantitative methods, provides a thorough and practical means to assess a system's usability [47]. This approach is particularly effective when the goal is to understand how a technological artefact is used in a real-world context. We employed this approach to gain a detailed understanding of how participants interacted with *SignIt!*'s various features. Based on our findings, we plan to refine *SignIt!* and subsequently carry out a larger technology acceptance study using a suitable model. It is important to note that we did not formally assess language acquisition but relied on participant feedback regarding any self-reported learning experiences that arose from their engagement with *SignIt!*. The study was approved by the Institutional Review Board at Microsoft Research Lab, India. During the study, participants were requested to use *SignIt!* and earn the five badges corresponding to the five main features of the game. Once this was completed, we requested that they fill out a short survey and optionally participate in a video interview to provide detailed feedback.

4.1 Procedure

The study was conducted in India from July to September 2022. Due to the aftermath of COVID-19, we conducted the study (including recruitment, *SignIt!* deployment, and post-study survey and interview) remotely. Participants were recruited via recruitment emails to the National Institute of Speech and Hearing (NISH), WinVinaya Foundation, and Enable India (EI), as well as snowball sampling. To be eligible, participants needed to have access to an Android smartphone, be 18 years of age or older, and have some level of proficiency in ISL and English. The study was conducted sequentially in three batches of six, six, and eight participants respectively. The bugs and challenges reported by each batch were used to make minor upgrades to the APK for the subsequent batch.

For each batch, once consent was obtained, participants were added to a WhatsApp group with two of the co-authors. This group was used to facilitate communication with the participants and also allow message exchange between the participants. The *SignIt!* APK was shared in this group, along with installation instructions. Within the next 24 hours, a 45-minute introductory session was conducted over the Zoom videoconferencing tool to provide participants with an overview of *SignIt!* and the research study and answer any of their questions. In addition to the participants, these sessions were attended

©International Telecommunication Union, 2023

Table 1 – Participants demography. Note that * indicates that the participant was interviewed

P.Id	Sex	Age	City	Education	Occupation	Deafness Level	Deaf Years
P1*	M	22	Trivandrum	Bachelor's	Student	Mild	22
P2*	F	21	Alappuzha	Bachelor's	Student	Mild	21
P3*	M	23	Delhi	Bachelor's	Student	Moderate	23
P4*	F	21	Pathanamthitta	High School	Student	Profound	21
P5*	F	22	Vatanappally	Bachelor's	Student	Profound	22
P6*	F	21	Delhi	High School	Student	Profound	21
P7*	M	21	Panchkula	Bachelor's	Student	Mild	21
P8*	M	23	Pune	Bachelor's	Student	Profound	23
P9*	M	31	Thiruvalla	Bachelor's	Not employed	Profound	31
P10*	F	22	Thrissur	Bachelor's	Student	Profound	22
P11*	M	25	Bangalore	Bachelor's	Working	Profound	25
P12*	M	22	Hyderabad	Bachelor's	Student	Mild	22
P13*	M	28	Tirunelveli	High School	Working	Profound	28
P14*	F	26	Piduguralla	Bachelor's	Working	Profound	26
P15*	M	29	Bangalore	Bachelor's	Working	Profound	29
P16	M	32	Wadakkanchery	Master's	Working	Profound	32
P17	M	23	Kochi	Bachelor's	Working	Profound	23
P18	M	26	Biratnagar	Bachelor's	Working	Profound	26
P19	M	32	Ahmedabad	High School	Working	Profound	30
P20	F	28	Malappuram	Bachelor's	Working	Profound	22

by two Deaf authors proficient in ISL and two hearing authors with basic ISL knowledge. One of the Deaf authors conducted the session in ISL. At the end of the session, participants were requested to earn Level 1 of the first five badges on *SignIt!*, which involved playing five individual quizzes, one group quiz, and three live quizzes, as well as creating one group and three quizzes. Two personalized reminders in English were sent to each participant daily based on their current usage, encouraging them to continue using *SignIt!* and earn their next badge. For instance, participants who primarily played individual quizzes were sent messages like '*Hello* name*! Hope you are having a great time using SignIt! Check out the create group feature to compete with your friends and try to stay on top of the leaderboard!*'.

After earning the badges, participants completed an online survey and optionally participated in a 45-minute semi-structured interview over a video call. The online survey began with demographic questions, followed by five-point Likert scale questions that rated the ease of using *SignIt!*, the experience of trying its five fundamental features, and the quality of signing on the app. The survey concluded with questions about the participants' prior experience with sign language games and their interest in downloading *SignIt!* if it were publicly released.

In the interview, we asked them about their overall experience of using *SignIt!*, their motivation behind using the app, any learnings they gained, challenges faced, and suggestions to improve *SignIt!*. We focused on quiz creation, particularly on identifying and recording quiz questions and options. Moreover, we asked them custom questions based on their play behaviour obtained from the log data, for instance, '*Your log file revealed that you played the same quiz on "Fun Puzzles" five times in the individual mode, why?*'. All interviews were conducted in ISL over Zoom by a Deaf author or by hearing authors interpreted by ISL interpreters. All the calls were recorded with the consent of the participants. Participants were informed that the data would only be used for research purposes. The participants were requested to uninstall *SignIt!* after their interview. The interviews were transcribed soon after they were conducted by the interviewer, and we use the exact translation when quoting participants. Participants were given an INR 700 (~10 USD) gift voucher of their preference for participation.

4.2 Data analysis

We conducted a mixed-method analysis to systematically analyze the data. Log files from participants' app usage were quantitatively analyzed to find overall statistics including the time spent on the app, number of quizzes started/completed in various modes, number of quizzes shared with other participants, and the number of quizzes created. We also performed thematic analysis to explore the themes that emerged from the interview data for our qualitative analysis. We subjected our interview data to open coding and categorized our codes to understand user behaviour. Two authors participated in the coding process and iterated upon the codes until a consensus was reached. Over the course of the analysis, they discussed coding plans, developed preliminary codebooks, reviewed the codebook, refined/edited codes, and finalized categories and themes. The first-level codes were

 ©International Telecommunication Union, 2023

very specific, such as "motivation to play" and "sharing quizzes". After several rounds of iteration, the codes were condensed into high-level themes, such as "challenges with comprehension", "learning", and "collaboration".

4.3 Participants

Our study included 20 participants (7 female, 13 male, age=24.9±3.75 years), with 12 participants from the National Institute of Speech and Hearing (NISH), five from WinVinaya Foundation, and three from Enable India. All participants in this study belonged to the DHH community. In terms of Indian Sign Language (ISL) proficiency, nine participants were experts, seven were intermediate, and four were beginners. Most participants had profound hearing loss (15), with one having moderate and four having mild loss. They resided in diverse locations across southern, western, and northern India, as well as Biratnagar, Nepal. In terms of education, 15 participants held undergraduate degrees, four had completed high school, and one had a master's degree. Of the 20 participants, 15 (6 female, 9 male, age=23.8$\pm$3.14 years) participated in the post-study feedback interview.

4.4 Authors' positionality

Three of the 10 authors are Deaf with ISL as their first language. All other authors are hearing with one author having beginner-level competence in ISL and three others having some familiarity with ISL. The hearing authors are native speakers of four Indian languages and have English as their primary professional language. Three of the authors self-identify as female and the rest as male. All of the hearing authors have prior experience working with and/or conducting studies with people with disabilities.

5. FINDINGS

Participants in our study engaged with the *SignIt!* app for an average of 9.2±7.7 days. During this period, they attempted a total of 1139 quizzes, averaging 56.95±40.22 quizzes per participant across all quiz play modes. Moreover, they created a collective total of 210 complete quiz questions, with an average of 10.5±8.7 quiz questions per participant. The participants dedicated a combined time of 86 hours and 31 minutes to using the app. Feedback from the participants revealed that they found the user interface of *SignIt!* to be easy-to-learn, intuitive, and accessible. They highlighted various reasons for using the app, such as passing time, learning English and ISL, exploring the quiz content, connecting with friends, and seeking recognition. These motivations played a significant role in their engagement with *SignIt!*. Below, we report the key findings from our study.

5.1 Role of sign language

SignIt! was developed with the goal of creating an accessible game-based learning platform for the DHH community, enabling players to play and create quizzes in sign language. In the post-study interview, when the participants were asked about their overall experience with *SignIt!*, 10 participants appreciated quizzes in sign language. Specifically, participants reported their struggles with English (as a second language), which has been well documented in accessibility literature [48, 2]. Although English was minimally used across the *SignIt!* app, our participants reported hard-to-understand English in the hints (captions) of quiz questions and in the Find Questions repository. For quiz creation, six participants did not choose any questions from the Find Questions repository, as they found the English to be "*too complicated to understand*".

The novelty and accessibility of sign language-based quizzes helped with the quick adoption and retention of *SignIt!* usage, with participants spending 28.2$\pm$13.24 minutes on *SignIt!* every day. We observed a large variance in the average daily usage, ranging from 6.8 minutes/day by P18 to 59.8 minutes/day by P14. P14 stated that she used *SignIt!* because "*I learned something new with everything [all quizzes played] ... when I finish my work, I'm usually free and have nothing to do, so I get bored. That's when I have no friends around also to talk to, so this was a good way to keep in touch with my friends and play.*" Three participants compared *SignIt!* to Kahoot! and preferred *SignIt!* as they find it difficult to understand the "*long English sentences*" in Kahoot! quizzes. For instance,

> "I have used Kahoot! before. In my experience, the long English sentences are confusing and hard to understand... *SignIt!*, wow, this is such a great thing for us. I can easily switch between ISL and English, so easy to use and kept me motivated. I felt good while using this app." – P3

Despite the sign language being more consumable, participants reported several difficulties in understanding ISL on *SignIt!*, due to regional variations in ISL, the speed of signing, and low video quality. First, the Indian Sign Language (ISL) is not a *single* language. It has a variety of regional dialects, such as the Bangalore-Chennai-Hyderabad Sign Language, Mumbai-Delhi Sign Language, and Kolkata Sign Language [49, 50], which have different signs for the same English word. In addition, DHH from rural India have minimal exposure to these standardized dialects, as they typically use an organically evolved 'home signing' system for communication [51, 52]. Two participants mentioned that some quizzes were signed in Kerala Sign Language (Note: Kerala is a state in India) and they were having difficulty understanding it.

> "I think the signers are from Kerala... the signing was a little different. So, basically, I didn't know those signs of the capital cities, so it was difficult for me to understand. If the deaf person could spell it like K-O-C-H-I (finger-spelled) I would understand." – P15

©International Telecommunication Union, 2023

A few participants reported difficulty understanding the quiz question and/or the options due to the use of "*non-standard signs*". One of the participants (P15) during the post-study interview explained to the researchers that "*it is an issue because SignIt! is a non-interactive platform*", i.e., it lacks two-way communication. Typically, when two DHH individuals communicate in different regional dialects of ISL, they clarify the meaning of their signs and/or ask the other person to finger-spell it in case of any confusion. Diversity and non-standardization of ISL is a known problem, and the National Education Policy of India, published in July 2020, aims to standardize ISL and create educational resources utilising the standardized form.

Second, participants raised concern about the signer's speed in the quizzes stating that "*it was too fast to follow*". This may be due to the time restrictions placed by *SignIt!* on the length of sign language recorded quiz videos, 30 seconds for a question, and 15 seconds for each option. These restrictions were added to ensure that the game remains fast paced. Finally, P5 complained about the lack of video quality, particularly "*hands moving out of the video frame*" while signing, in a few quizzes she played. In spite of providing real-time feedback (like move closer/far, move left/right, multiple faces) to the participants for quiz creation video recordings, we identified a few videos with parts of hands/faces getting cropped.

5.2 Participants motivation to learn

One of the major motivations for our players to use *SignIt!* was learning, specifically acquiring general knowledge from the quiz content, and improving their ISL and English language skills. On average, our participants attempted 32.9 ± 22.2 quizzes (wherein they answered one or more questions), ranging from 3 to 89 quizzes across participants. In the individual mode, participants played an average of 23.5±16.48 quizzes, despite a minimum threshold of 5 quizzes set by researchers, suggesting that participants were intrinsically motivated to play quizzes in *SignIt!*. Participants mentioned a variety of reasons to play quizzes, including "*to learn new things*" (8 participants), "*to compete with friends*" (6),"*it's fun*" (6), "*to pass time*" (3), and "*to earn badges*" (2). Similar motivations have been reported in previous digital games-related studies [53, 54]. Interestingly, P10 stated that she played particular quizzes to help with her exam preparation. From the log data, we found that P10 played two mathematics-based quizzes and 11 general knowledge-based quizzes on topics such as geography, sports, and computers. This hints that similar to Kahoot!, *SignIt!* has the potential to be used as a learning platform.

To further understand the quiz play behaviour, we grouped the most played quizzes according to their tags. The five most popular tags among our participants were riddles (215 plays, 3 quizzes), geography (127 plays, 8 quizzes), computers (112 plays, 6 quizzes), Deaf culture (109 plays, 3 quizzes), and sports (87 plays, 7 quizzes). An example of a riddle quiz question: *What is always coming but never arrives?*, with the answer being *Tomorrow*. This emphasis on playing riddles shows that fun was the key reason behind playing quizzes; however, our participants attempted quizzes related to geography, science and technology, and sports, to learn more about these topics. Two participants also requested explanations of the answers and/or providing more information related to each question-answer pair, to aid in the learning process.

While we did not test the retention of acquired knowledge of our participants, we found anecdotally that several participants (5) recalled learning about popular topics, such as "*I learned how many MLAs are there in India*" – P9. Interestingly, our participants found it hard to remember the finger-spelled answer (compared to signed answers). For instance, "*I learned about who is the father of mathematics? However, there was no sign name for that person. So they (finger) spelled his name. The name was very long so I forgot.*" – P12. We found participants played the same quiz multiple times, mainly to improve their learning, to check their retention of the quiz content, and to increase their highest score. For instance:

> "Yes, I played the quiz, but my answers were wrong for some questions. I learned which of my answers were mistakes... I tried again and played the same quiz... That's how I improved my knowledge." – P6

In our study, 19 out of 20 participants repeated one or more quizzes. The maximum number of times a quiz was repeated was seven (by three participants). Out of the 137 instances of a quiz being repeated, the number of correctly answered questions increased in 75.9% of the cases. Kahoot! players have been found to show similar game play behaviour of playing quizzes multiple times [55].

In addition to learning from the quiz content, participants reported learning language skills, in particular English words and ISL signs, from the ISL-to-English mappings in questions and options. For instance:

> "It [quizzes] helped me learn English... For example, dog's baby is known as puppy. I was not aware of that. I would think dog baby would be called 'baby', but every animal's children, I mean baby have a different name, that is a good thing I learned." – P15

For context, in ISL, the word puppy is communicated by signing 'dog' followed by 'small'. Several words and concepts in English lack an equivalent sign in ISL, resulting in such knowledge gaps. Apart from vocabulary, participants suggested incorporating quizzes on English grammar topics such as tenses and pronouns, to help them further improve their English.

Three participants mentioned learning sign language from *SignIt!*. They preferred learning from options, as it comprised of words or short phrases, making it easier

 ©International Telecommunication Union, 2023

to learn sign language-to-English mapping. Participants mentioned two main reasons for not being able to learn ISL from quiz questions, the difficulty of matching individual signs with the corresponding English words in the sentence and the fast pace of the signing, making it challenging to follow.

Apart from learning by playing quizzes, our participants also gained general knowledge, learned English words and ISL signs, through quiz creation. Four participants mentioned learning "*new facts*" while searching for content for their quizzes. For example,

> "I am a nature fan and an animal lover. You may think that giraffe have just one stomach like everyone else, but Giraffe has four stomachs, so that is really, really nice to know... Learning such details about different animals was very cool. I got this information online (while creating an animal quiz)." – P15

Other participants provided similar examples of learning about sports, Indian politicians, and multinational companies.

5.3 Collaboration within community

Prior work has demonstrated that group play is typically more engaging than individual play because playing in a group fosters competition and collaboration [22]. Even in our study, we discovered that elements of group play such as group quiz and live quiz in *SignIt!* was preferred by our participants. A total of 132 group quizzes and 56 live quizzes were played during the study duration. Our participants created 46 groups, with an average of 4.7 ± 2.7 members/group, and in total shared 75 quizzes in these groups.

Most of our participants were acquainted with each other prior to the study. That might have played a role in their readiness to form groups, and play live and group quizzes. As P14 said: "*I connected with my friends, like P13 and P15, using the group mode... It was nice to connect with different friends and play. It was very simple.*" Our participants used groups as a way to stay connected with each other and as a forum to share and discover quizzes. Three participants stated that they added quizzes on topics that they wanted their friends to learn about. For example:

> "The group mode is useful because my friends don't know about these different topics. I either share existing quizzes or my created quizzes with them, so that they will learn from these quizzes... They will gain knowledge after playing quizzes." – P6

Interestingly, 64% (48 out of 75) of the quizzes shared in these groups were created by the group creators themselves. This indicates that participants created these groups mainly to promote their own quizzes. Aside from sharing quizzes, three participants stated that they enjoyed joining groups to get access to quizzes vetted by others. The log analysis showed that two of these participants were in approximately 30 groups each, and played at least one quiz in a majority (26 and 23) of their groups. Groups enabled participants to effectively share and consume content, with a sense of belonging to the *SignIt!* community.

To create a group in *SignIt!*, participants need to add other *SignIt!* users from their saved contacts. However, once the group is formed, all group members were represented by their randomly generated usernames. While this anonymity protected participants' privacy, some participants complained that they found it challenging to identify their friends in the group. As a workaround, six participants updated their default random usernames to their original full names, so that others can identify them. In addition, one participant wanted to upload their headshot instead of the avatar image to further help others. This shows that participants willingly de-anonymized themselves in order to socialize more effectively. Not only that, participants requested showing online status of their friends on *SignIt!*, a feature available in popular social media platforms. This was mainly to help them coordinate a time to play live quiz with their friends.

> "For live quizzes, my friends didn't have time to play together the quizzes game due to their study or assignment. I could play individual quizzes instead." – P6

Besides playing with other study participants, 5 out of 16 participants expressed their willingness to share *SignIt!* with their other friends. Interestingly, P9 saw potential to connect with DHH individuals across borders:

> "I think this can be an international game where we can meet deaf people from across the world. It will be more of, like, people can play and share things... they can spend hours in this, play game, socialise and talk about deaf culture of different countries. There's a lot of possibilities through this app. I want to play with my friends, and also, I want to meet new people here." – P9

To enable meeting new people on *SignIt!*, it needs to display all *SignIt!* players to everyone, instead of just players' saved contacts.

The key reason behind our participants' enthusiasm for group and live quizzes was the element of competition. Prior research has shown several positive outcomes of competition in game-based learning such as increased intrinsic motivation, greater attention and excitement, more collaborative work, and active participation [56, 57, 58, 59]. We observed similar patterns in our study. Our participants stated that the competitive element in live quizzes kept them "*motivated and interested*", with three participants mentioning that at times they got "*bored*" playing individually. Specifically, since the leaderboard was displayed after every question, the players were motivated to perform better by answering correctly and quickly.

©International Telecommunication Union, 2023

> "I got bored when I was playing individual mode alone. I enjoyed group mode games with other members because there is competition like a fight to win the game." – P8

Similarly, in group mode, participants checked the group leaderboard often, in total, 166 times by 15 participants, 11.1$\pm$6.4 times each participant, to view their position and to "*see my friends' results*". Log analysis with the Kruskal-Wallis test revealed a significant effect of quiz play mode on quiz completion (χ_2=7.017, p<0.05). A post-hoc test using Mann-Whitney tests with Bonferroni correction showed the proportion of completed group quizzes (83.5%) to be significantly higher than individual (36.5%) and live (35.2%) quizzes, with p<0.05. This may be due to the asynchronous nature of group quiz play, enabling the players to play at their convenience, along with facilitating an environment of social competitive play. To further illustrate this competitive behaviour, P1 requested notifications for when a new quiz gets added to any of his groups, because "*I was not aware when the member added the quiz, I had to check myself. I was one or two days late when I saw there are two to three quizzes, I want to get the notification that there are quizzes which are ready*".

The motivation to top the leaderboard has negative consequences as well. 13 out of the 22 participants tried to game the system. From the log data, we found that in 46 instances, our participants played the quiz in individual mode before attempting it in group mode to gain an unfair advantage and score high. Similar behaviours were observed before initiating and attempting a live quiz as well.

5.4 Participants enthusiasm to create content

Our participants created 82 quizzes containing 210 valid questions and 46 incomplete questions, with an average of 3.1$\pm$1.8 questions per quiz. A majority (14) of our participants rated the quiz creation interface to be easy to learn and use. In particular, P1 commented:

> "I liked creating quizzes on *SignIt!*. I really liked it a lot. I mean, this is the first time I made a quiz using my own ideas. Earlier I used to think how I can make quiz. So this was something new for me and I learned as well." – P1

In spite of the minimal learning curve of quiz creation, it was the most complex task on *SignIt!*, as it involved identifying quiz questions with a minimum of two options, recording sign language videos, and entering corresponding English text for each question and its options. Our participants reported several motivating factors for quiz creation, including improving their knowledge (discussed in Section 5.2), helping the DHH community, earning coins and badges, and acquiring fame.

Four participants stated that they created quizzes to "*impart knowledge to Deaf people*" through their quizzes. These participants primarily created quizzes about India (on capitals of cities, languages spoken, and traditional food), world geography, animals, and computers, i.e., on specific topics which they thought were useful for the DHH community to learn about. Interestingly, one participant stated fame as a motivator for quiz creation. The prospect of acquiring 'fame' on *SignIt!* meant that when other players will play the quizzes created by our participants, the players will start recognizing the quiz creators through it. For example, P1 stated:

> "To make a quiz, I need to sign as well. I really like it... I think that it's going to be great, as it is something made by me, and others will see it... Other people will click and they will see my video. I will automatically become famous." – P1

To quantify fame, we count the number of times a quiz has been played, similar to the concept of views on YouTube. We found that P1 quizzes have been played 52 times, compared to the average of 12.8$\pm$19.5 plays across other participants.

Our participants created an average of 10.5$\pm$8.7 valid questions (minimum=0 question, maximum=25 questions). Out of the total 210 valid questions, our participants created 74 using the Find Questions repository and 136 using external sources (including Google, YouTube, and the National Geographic TV channel). Five participants preferred using the Find Questions repository despite its limited number of questions and categories, due to the convenience and ease offered by it. For instance,

> "It takes very long to make quizzes on my own because I need to think, I need to research... that's very difficult. So the easier option and the quicker option was to just sign whatever was already there [in the repository]." – P14

Other participants also used the repository when they were "*out of ideas*" for new quizzes. In contrast, five participants did not use this feature at all, mainly because the English text in the repository questions was too difficult to understand, and they wanted to avoid creating duplicate questions on *SignIt!*.

With respect to adding sign language videos to the questions and corresponding options, multiple participants praised the video recording interface which effectively guided them to adjust their distance from the camera. The automated feedback was beneficial for our participants as they were not accustomed to recording themselves. To improve this interface further, our participants suggested adding a trim tool to help cut the end of the recording (wherein the creator taps the 'Stop' button), adding a feature to upload videos from the gallery, and recording videos horizontally for "*more signing space*".

The authors manually analyzed the questions created by our participants to evaluate them on factual correctness and grammar, and categorize them. Overall, 89.5% of the questions were factually correct, unambiguous, and

 ©International Telecommunication Union, 2023

had one correct answer. Out of the remaining questions, 6.2% had incorrectly marked answers and 4.3% questions were ambiguous. An example of an ambiguous question from a cricket-based quiz was '*Who made 6 sixes in 6 balls?*' wherein two options were correct. An example of an incorrectly marked answer was "*Which is the most populated country in the world*" where 'China' was marked as the answer, while 'China' was the correct answer at the time the participant created the question, 'India' surpassed it recently and was the correct answer at the time of analysis. Through this analysis, we found that questions based on political figures, records, etc. could become outdated and would need to be updated by the quiz creator to prevent misinformation. In addition, 20 questions had minor grammatical errors such as missing articles, incorrect prepositions, and interchange of singular and plural verbs; however, the questions were understandable. With respect to category, the most common questions were about animals (24), cricket (23), India (23), computers (12), and mathematics (12). Participants chose quiz topics based on their personal interests, popular interests, and usefulness of the content for the DHH community. For instance, "*I'm collecting feedback from Deaf people about their interests. They're saying they want more questions about MS Office, Excel, Word, Tally, etc. software.*" – P15. Subsequently, P16 created a quiz on Microsoft Excel with five questions on charts, rows, and keyboard shortcuts.

Participants actively encouraged other participants to play their quizzes and even advertised them, by adding their quizzes to groups (discussed in Section 5.3), starting their quizzes in live mode, and sharing links to their quizzes on their WhatsApp group. Out of the 12 participants who shared quiz links, 10 participants shared their own quizzes an average of 4.3 ± 2.5 times. In addition, participants mentioned sharing their quizzes in live and group mode mainly to see how their friends would perform. As quiz creators, our participants were deeply invested in how their quizzes were performing in terms of number of plays on *SignIt!*. Our log analysis showed that participants played their own quizzes on an average of 10.7 ± 18.0 times, ranging from 0 to 67 times. Surprisingly, 14 out of 20 participants started their quizzes and exited them without answering any question, more than twice. One possible explanation for such behaviour could be to increase their number of quiz plays. Similar behaviour has been reported by prior studies exploring content creation on media platforms such as YouTube [60]

5.5 Collection of sign language video data

Through our user study, we collected a total of 2931 sign language videos (total duration of 3 hours and 12 minutes), along with their corresponding English text labels. These videos were recorded in real-world settings (e.g., homes, hostels, and workplaces) by signers across genders and geographical locations, and thus captured the regional variations of ISL. To facilitate the two fundamental machine learning tasks, isolated and continuous sign language recognition, we divided the collected sign language data into two distinct datasets. While the isolated sign language dataset comprised of videos with single-word annotations (from quiz options), the continuous sign language dataset included videos with short phrases and sentences (from quiz questions and options). The isolated sign language dataset consisted of 1573 videos, with 751 unique words such that 95 words were signed by three or more users. The continuous sign language dataset included 1358 videos of sentences, with a vocabulary of 1948 words such that 390 words were signed by three or more users. The maximum number of occurrences of the term "false" is observed in 26 isolated sign language videos, whereas the maximum number of occurrences of the term "many" is observed in 63 continuous sign language videos. Detailed statistics of the datasets can be found in Table 2.

To evaluate the quality of the data collected, the authors randomly sampled 100 videos from both the isolated sign language and continuous sign language datasets. Similar to prior work [11], they employed a certified ISL interpreter to manually evaluate the accuracy of the English hints used as labels for the sign language videos on a five-point Likert scale. The scale ranged from 1, very inaccurate, to 5, very accurate. The authors also manually reviewed each sign language video to check for video quality issues.

In the isolated sign language dataset, the annotations received an average rating of 4.5 ± 0.8, with 72 videos rated as very accurate (5). Of the remaining 28 videos, 17 had lower ratings because of regional dialects used and finger-spelling for common words. The other 9 videos received lower ratings because they were incomplete, incorrect, or not clear enough to evaluate. In terms of video quality, 85 videos had ideal lighting and placement of the signer. However, seven videos had a slight lag in the videos, two had stretching artefacts due to the cropping around signers, four had poor lighting, and two had low resolution. Based on these issues, there is a need to improve the recording interface to assist signers in future iterations.

In the continuous sign language dataset, the annotations received an average rating of 4.3 ± 1.1, with 66 videos rated as very accurate (5). Of the remaining 28 videos, 13 had lower ratings because of regional variations, incorrect sign language phrasing, and finger-spelling. The other 15 videos were incomplete or had incorrect signs, which could be due to the 15-second limit imposed on signed videos in *SignIt!*. In terms of video quality, 83 videos were of good quality, 10 had low resolution, and 3 had poor lighting. Additionally, 4 videos had blurred hands due to lag while recording.

6. DISCUSSION

SignIt! is an example of co-development of an accessible quiz platform with the DHH community. Our study revealed many issues that detract from learning on *Sig-*

Table 2 – Key details of the collected datasets

Characteristic	Isolated SL Dataset	Continuous SL Dataset
Number of signers	20	20
Number of videos	1573	1358
Vocabulary size	751	1948
Average video length (sec)	3.5±1.4	6.7±3.7
Min./Max. video length (sec)	0.6 / 12.4	0.5 / 26.3
Average words per video	1	5.5±4.4
Total duration	1H 6M	2H 7M
Max. # of videos for a word	26	63
Frame rate, Resolution	30, 512x512	30, 512x512

nIt!, such as difficulty from long sentences, difficulty recalling names due to a lack of corresponding signs in ISL, and regional variations. Additionally, *SignIt!* enables the DHH community to create diverse content. We discuss the challenges with a sign language-based user-generated content platform, such as content moderation, labour of creation, and privacy. Since quiz creation leads to a large amount of labelled sign language data, we discuss the different ways to ensure that the data generated aligns with the requirement of ML models, and guardrails for transferring this generated content for open-source development of ML models. Based on these findings and prior work, we subsequently explore these issues in further detail, how platforms might mitigate these issues and the recommendations for future apps that support user-generated sign language content.

6.1 Learning as a positive motivation and outcome

Our study findings highlight *SignIt!* as a versatile learning tool, that caters to various learning scenarios. The platform is specifically designed to accommodate individuals with different levels of proficiency in ISL and English, allowing for simultaneous learning of both languages. The Indian DHH community exhibits significant diversity in language proficiency in both ISL and English, influenced by factors such as schooling background, age of exposure to sign language, and the presence of local languages in different regions of India. *SignIt!* recognizes and supports this diversity by enabling players to interchangeably leverage their existing knowledge in one language to learn the other, in contrast to general game-based language learning platforms that assume expertise in one language and teach another. Within our study, we observed three distinct learning scenarios.

The first scenario focused on the discovery and learning of new vocabulary in English and ISL while playing quizzes. Vocabulary learning usually took place from the options of the multiple choice questions since they contained single words or short phrases. For example, P15 encountered an unfamiliar English word, puppy, and found that animal children have specific names in English. Interestingly, P12 couldn't remember the name of the father of mathematics since the name was long and the ISL component was finger-spelled. There are several words and concepts in English that do not contain direct equivalent signs in ISL. In such cases, the words are either conveyed using a combination of words or by finger-spelling. With respect to sign language, P15 faced challenges in comprehending signs for Indian capital cities since the quiz contained an unfamiliar regional variation of ISL. We recommend future sign language learning platforms consider the regional variations in sign languages and have an option to indicate the specific region of the content if available, this would enable users to make informed decisions to engage with the content based on their familiarity or curiosity regarding the specified regional sign language variation. Exposure to regional variations facilitates communication between diverse DHH communities and enriches the learning experience. Therefore, discovering new and diverse vocabulary in both languages while playing quizzes is critical to learning. However, the retention of new vocabulary is a challenge and depends on the frequency with which participants encounter and use the words subsequently. Research shows that repetitive exposure to a certain subject matter promotes learning [61]. Many of our participants also played quizzes multiple times to solidify their understanding and retention of the information. In contrast to options, we found that participants found it challenging to learn from the questions since they contained longer sentences. The differences between English's Subject-Verb-Object (SVO) structure and ISL's Subject-Object-Verb (SOV) structure, coupled with the absence of connectives and articles in ISL, made it difficult to establish correspondences between individual words in a sentence. In summary, this scenario portrays instances of unstructured and incidental learning during gameplay.

The second scenario involved participants using *SignIt!* as a conventional quiz platform to enjoy quizzes in ISL while occasionally picking up new information. Since there is a dearth of information present in ISL, participants appreciated engaging in diverse content in their native language (ISL). Interestingly, we found that participants created quizzes on useful topics with the goal of imparting knowledge to the wider DHH community. They

 ©International Telecommunication Union, 2023

encouraged their friends to learn and used groups as a forum to share and discover quizzes. While learning general facts from the quizzes was not the main objective of *SignIt!*, it was a significant and positive learning outcome of the app.

The third learning scenario involves learning while creating quizzes. To create a quiz, our participants searched for relevant quiz material from external sources. Moreover, they added suitable sign language and English translations for the questions and options. Since this process required our participants to actively fill in the gaps in their knowledge and spend more time with the quiz, we believe that it led to a broader and more comprehensive learning experience compared to the other scenarios.

6.2 Agency of content creation

In our user study, we found that our participants created a rich and diverse sign language quiz platform containing almost 3000 sign language videos that covered fun topics, educational syllabus-based topics, general useful worldly information, and even Deaf-specific topics such as Deaf culture. This is significant as the amount of quality content accessible by the Deaf across these topics is sparse.

Further, our participants not only prioritized accurate sign language but also took care to provide hints in simplified English, making the content more accessible to players with varying levels of language proficiency. This suggests that *SignIt!* and similar such efforts hold promise in being a platform where the Deaf community experiences and exercises the agency to create content for other members of their community. While the participants found the quiz creation interface easy to use, the process as the quiz creator was time-consuming as they not only needed to find the quiz content but also enter the question and four options in both sign language and English. We recommend future platforms support sign language content generation in a way that reduces the labour of this task. For instance, creating a library where quiz creators can add sign language to text pairs. These pairs may be reused as necessary (in the case of *SignIt!*, for reusing across multiple questions and quizzes). This would reduce the labour of the quiz creator while also bringing some uniformity to the content. Since *SignIt!* users were given complete agency over their creations, the responsibility for ensuring the correctness of the information presented, as well as the sign language videos and translations, rested entirely on them.

In our analysis, we found inaccuracies, ambiguities, and minor grammatical errors in a small proportion of the questions. Though these issues did not have any consequences in our study, it is crucial for user-generated sign language content platforms to have content moderation before being released publicly to prevent misinformation. For *SignIt!*, we propose that a content moderation feature should check each question created and notify the quiz creator if there are any mistakes. Additionally, the feature should periodically check all questions in *SignIt!* to ensure that the facts presented in the quizzes are up to date. This iterative refinement process may also hold pedagogic value and may be incorporated as part of formal educational programmes.

While manual content moderation may lead to accurate content, it may not be scalable. An alternative is to use machine learning models to evaluate features of videos such as lighting, hands going out of frame, and other factors immediately after recording a video to guide the creator. Machine learning-based grammar checkers may also be incorporated to verify the correctness and suggest changes to the text entered by the creator. As machine learning models for auto-recognition of sign language [62] get better with the creation of more open data resources, we hope for more automated feedback on the signing quality in the future. Crowdsourcing feedback from users of the app is also a potential option.

Our study revealed that many participants were driven by various motivators to create quizzes, including the desire to learn, share knowledge, earn coins and badges, and gain fame. This is similar to the notions of fame in the social media platforms such as TikTok and Instagram, where the viral visibility of one's video is considered a measure of success of the content creator. A quantitative measure of 'fame' on *SignIt!* is the number of plays of the quiz. Our participants actively encouraged other participants by sharing their quizzes in groups and hosting live-mode quizzes with their quizzes. This positive feedback loop must be further enabled to scale engagement within the community. On the other hand, some participants did demonstrate concerns with privacy by sharing their quizzes only with friends in private *SignIt!* groups. To empower such participants, technologies such as augmented reality can be considered by creating avatars that mimic a person's actions and facial expressions with high fidelity while generating the quizzes.

6.3 Feasibility of data collection

Research on building machine learning tools to recognize sign language is stymied by the lack of open data resources at the scale required to train modern neural networks. We demonstrated that *SignIt!* can be a platform for such data collection at scale. In total, 2936 labelled videos were collected and were manually verified by ISL experts to be moderate to a high quality. We believe that with greater focus on processes and technologies to maximize data accuracy, engaging play can be a successful way to create large datasets for sign languages.

Our immediate concern is the word distribution in the data. We found that across the videos, the frequency of each word was low at a frequency of $\approx$2 for each word. While this indicates diversity in content, it impedes the creation of machine learning models which need a large number of labelled examples for every sign to be classified. One way to address this is to specifically curate questions in the Find Questions repository that have a desired distribution of words, for instance, multiple occurrences

©International Telecommunication Union, 2023

of the top 1000 words that a sign language student may want to be proficient at.

However, it is important to note that privacy and data governance be strictly followed in such efforts. We received consent from participants for the data use. We are also developing a data processing pipeline capable of anonymizing any given video by extracting features essential for sign language recognition, such as hand, face, and body pose coordinates. To manage the data within ethical boundaries, we are considering a partnership with an academic institution to host *SignIt!*. This collaboration will enable the collection of sign language data for global research initiatives in automatic sign language recognition under open licensing.

6.4 Limitations and future work

This study has some limitations that suggest directions for future work. First, we only recruited 20 participants for a short-term study, which limits the generalizability of our findings to a broader population of DHH individuals. Based on the insights from this study, we plan to refine *SignIt!* and subsequently conduct a more extensive, long-term study. This future study will evaluate technology acceptance using standardized metrics such as the System Usability Score (SUS) [63] and the Technology Acceptance Model [64]. It will also investigate the real-world usage of *SignIt!*, identifying potential challenges and necessary adaptations for sustained use. Second, we did not conduct a formal learning assessment to measure the effectiveness of *SignIt!* as a learning tool. Instead, our study focused on exploring the user experience and gameplay of DHH individuals using the app. A future study should evaluate the learning outcomes achieved by users on *SignIt!* using predefined learning objectives and metrics, such as knowledge retention, language proficiency improvements, and overall learning gains. Additionally, future research could explore various avenues for further enhancing *SignIt!* as an educational tool for diverse demographics. Building upon the success of Kahoot! in classrooms, evaluating *SignIt!* as an educational tool for Deaf and Hard-of-Hearing (DHH) children in classroom settings could be a valuable next step. This evaluation could involve integrating *SignIt!* into the formal education curriculum and assessing its impact on learning outcomes for DHH students. Moreover, it would be interesting to explore the potential of *SignIt!* as a learning tool for hearing individuals using sign language, including friends and family of DHH individuals, as well as sign language students, which would expand the user base and promote inclusive language learning. Finally, we hope to work with DHH communities from different countries and cultures to understand how *SignIt!* could accommodate different sign languages and caption languages, and address their unique needs and challenges.

7. CONCLUSION

In this work we presented *SignIt!*, an accessible app-based gaming experience, which was developed as a result of a deep collaboration with the DHH community in India. *SignIt!* enables participants to create and solve quizzes with questions and multiple-choice options signed in Indian Sign Language (ISL). Through a detailed study with DHH participants, we were able to establish three key findings. First, the app affords learning opportunities for participants within an engaging setup. Their learning spans multiple domains, the subject matter covered in the questions, English vocabulary, and ISL signs. Second, the app effectively encourages social collaboration between participants in sharing and playing quizzes. It also shows early promise to allow mixed-ability groups to interact. And third, the app empowers participants with the agency to be content creators. The generated content is valuable since it creates sign language videos on different domains and can contribute to more accurate machine learning models for sign language recognition. Given the potential demonstrated with *SignIt!*, and its generalizability to sign and text languages, we hope to expand this research by collaborating with different organizations and scaling up real-world usage.

8. ACKNOWLEDGMENTS

We express our gratitude to Sneha Santosh, Sreelakshmi N.J, and Snehal P. S, interns at MSR and students of NISH, for their valuable assistance in testing the early version of *SignIt!*. We extend our appreciation to the National Institute of Speech and Hearing for their collaborative efforts, and we are thankful for the significant contributions of Sandeep Krishnan, Arun Gopal, and Aswathy Vinod.

REFERENCES

[1] World Health Organization. “Deafness and hearing loss”. en. In: (Apr. 2021). URL: https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss.

[2] Advaith Sridhar, Roshni Poddar, Mohit Jain, and Pratyush Kumar. “Challenges faced by the Employed Indian DHH Community”. In: *Proceedings of the 19th IFIP TC13 International Conference on Human-Computer Interaction (INTERACT)*. Springer, 2023.

[3] Kalyani Mandke and Prerna Chandekar. “Deaf education in India”. In: *Deaf Education Beyond the Western World: Context, Challenges, and Prospects* 261 (2019).

[4] National Institute on Deafness and Other Communication Disorders. “Quick Statistics About Hearing”. en. In: (Mar. 2021). URL: https://www.nidcd.nih.gov/health/statistics/quick-statistics-hearing#2.

 ©International Telecommunication Union, 2023

[5] In: *National Programme for the Prevention amp; Control of Deafness (NPPCD)* (). URL: https://www.nhm.gov.in/index1.php?lang=1&level=2&sublinkid=1051&lid=606.

[6] Mohammad Shamim Ansari. "Assessing parental role as resource persons in achieving goals of early detection and intervention for children with hearing impairment". In: *Disability, CBR & Inclusive Development* 25.4 (2014), pp. 84–98.

[7] Philip B O'Keefe. *People with disabilities in India: From commitments to outcomes*. Tech. rep. The World Bank, 2007.

[8] Social and Rural Research Institute. "National Sample Survey of Estimation of Out-of-School Children in the Age 6–13 in India". In: (2014).

[9] Ali Yavar Jung National Institute of Speech and Hearing Disabilities. "Special Schools for Hearing Impaired Children in State/UT Hearing". In: (n.d.). Accessed on May 4, 2023.

[10] Australian Human Rights Commission. "United Nations Convention on the Rights of Persons with Disabilities (UNCRPD)". In: (n.d.). URL: https://humanrights.gov.au/our-work/disability-rights/united-nations-convention-rights-persons-disabilities-uncrpd.

[11] Danielle Bragg, Naomi Caselli, John W. Gallagher, Miriam Goldberg, Courtney J. Oka, and William Thies. "ASL Sea Battle: Gamifying Sign Language Data Collection". In: *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. CHI '21. Yokohama, Japan: Association for Computing Machinery, 2021. ISBN: 9781450380966. DOI: 10.1145/3411764.3445416. URL: https://doi.org/10.1145/3411764.3445416.

[12] Razieh Rastgoo, Kourosh Kiani, and Sergio Escalera. "Sign language recognition: A deep survey". In: *Expert Systems with Applications* 164 (2021), p. 113794.

[13] Susan Gregory. "Bilingualism and the education of deaf children". In: *Bilingualism and the Education of Deaf Children: Advances in Practice, University of Leeds, UK* (1996).

[14] Ofelia García. "Bilingual education". In: *The handbook of sociolinguistics* (2017), pp. 405–420.

[15] Ellen Bialystok. "Bilingual education for young children: Review of the effects and consequences". In: *International journal of bilingual education and bilingualism* 21.6 (2018), pp. 666–679.

[16] Ludic Design. "Language and Literacy". In: (n.d.). URL: https://www.ludicdesign.org/.

[17] Gesu India, Mohit Jain, Pallav Karya, Nirmalendu Diwakar, and Manohar Swaminathan. "VStroll: An Audio-Based Virtual Exploration to Encourage Walking among People with Vision Impairments". In: *The 23rd International ACM SIGACCESS Conference on Computers and Accessibility*. ASSETS '21. Virtual Event, USA: Association for Computing Machinery, 2021. ISBN: 9781450383066. DOI: 10.1145/3441852.3471206. URL: https://doi.org/10.1145/3441852.3471206.

[18] Gesu India, Geetha Ramakrishna, Joyojeet Pal, and Manohar Swaminathan. "Conceptual Learning through Accessible Play: Project Torino and Computational Thinking for Blind Children in India". In: *Proceedings of the 2020 International Conference on Information and Communication Technologies and Development*. ICTD '20. Guayaquil, Ecuador: Association for Computing Machinery, 2020. ISBN: 9781450387620. DOI: 10.1145/3392561.3394634. URL: https://doi.org/10.1145/3392561.3394634.

[19] Roshni Poddar, Pradyumna YM, Divya Prabha Jayakumar, Tarini Naik, Punyat Tripathi, Nabeel TP, Hemanth Reddy Yeddula, Pratyush Kumar, Mohit Jain, and Manohar Swaminathan. "SignIt! An Android Game for Sign Bilingual Play". In: *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ASSETS '23. New York, NY, USA: Association for Computing Machinery, 2023. DOI: 10.1145/3597638.3614484. URL: https://doi.org/10.1145/3597638.3614484.

[20] Jean M Twenge, Gabrielle N Martin, and Brian H Spitzberg. "Trends in US Adolescents' media use, 1976–2016: The rise of digital media, the decline of TV, and the (near) demise of print." In: *Psychology of Popular Media Culture* 8.4 (2019), p. 329.

[21] Isabela Granic, Adam Lobel, and Rutger C. M. E. Engels. "The benefits of playing video games." In: *American Psychologist* 69.1 (Jan. 2014), pp. 66–78. DOI: 10.1037/a0034857. URL: https://doi.org/10.1037/a0034857.

[22] Mohit Jain, Jeremy Birnholtz, Edward Cutrell, and Ravin Balakrishnan. "Exploring Display Techniques for Mobile Collaborative Learning in Developing Regions". In: *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*. MobileHCI '11. Stockholm, Sweden: Association for Computing Machinery, 2011, pp. 81–90. ISBN: 9781450305419. DOI: 10.1145/2037373.2037388. URL: https://doi.org/10.1145/2037373.2037388.

[23] Helene Brashear, Valerie Henderson, Kwang-Hyun Park, Harley Hamilton, Seungyon Lee, and Thad Starner. "American Sign Language Recognition in

Game Development for Deaf Children". In: *Proceedings of the 8th International ACM SIGACCESS Conference on Computers and Accessibility*. Assets '06. Portland, Oregon, USA: Association for Computing Machinery, 2006, pp. 79–86. ISBN: 1595932909. DOI: 10.1145/1168987.1169002. URL: https://doi.org/10.1145/1168987.1169002.

[24] Nicoletta Adamo-Villani and Kelly Wright. "SMILE: An Immersive Learning Game for Deaf and Hearing Children". In: *ACM SIGGRAPH 2007 Educators Program*. SIGGRAPH '07. San Diego, California: Association for Computing Machinery, 2007, 17–es. ISBN: 9781450318303. DOI: 10.1145/1282040.1282058. URL: https://doi.org/10.1145/1282040.1282058.

[25] Leigh Ellen Potter, Jessica Korte, and Sue Nielsen. "Sign My World: Lessons Learned from Prototyping Sessions with Young Deaf Children". In: *Proceedings of the 24th Australian Computer-Human Interaction Conference*. OzCHI '12. Melbourne, Australia: Association for Computing Machinery, 2012, pp. 501–504. ISBN: 9781450314381. DOI: 10.1145/2414536.2414613. URL: https://doi.org/10.1145/2414536.2414613.

[26] Raouf Chebka and Fathi Essalmi. "A crosswords game for deaf". In: *2015 5th International Conference on Information & Communication Technology and Accessibility (ICTA)*. 2015, pp. 1–6. DOI: 10.1109/ICTA.2015.7426880.

[27] Jintao Nie, Yijun Zhao, Bing Yao, Zheng Xu, jiayan Chen, Changchao Yu, Preben Hansen, Jianhui Liu, Jiadi Wang, Ge Yan, et al. "SignFind: A Synchronized Sign Language and Chinese Character Teaching Game for Chinese Deaf Children Using Gesture Recognition". In: *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. 2022, pp. 1–7.

[28] Diego Roberto Antunes and Janaine Daiane Rodrigues. "Endless Running Game to Support Sign Language Learning by Deaf Children". In: *Universal Access in Human-Computer Interaction. Access to Media, Learning and Assistive Environments*. Ed. by Margherita Antona and Constantine Stephanidis. Cham: Springer International Publishing, 2021, pp. 25–40. ISBN: 978-3-030-78095-1.

[29] Jestin Joy, Kannan Balakrishnan, and M. Sreeraj. "SignQuiz: A Quiz Based Tool for Learning Fingerspelled Signs in Indian Sign Language Using ASLR". In: *IEEE Access* 7 (2019), pp. 28363–28371. DOI: 10.1109/ACCESS.2019.2901863.

[30] Yosra Bouzid, Mohamed Ali khenissi, and Mohamed Jemni. "The Effect of Avatar Technology on Sign Writing Vocabularies Acquisition for Deaf Learners". In: *2016 IEEE 16th International Conference on Advanced Learning Technologies (ICALT)*. 2016, pp. 441–445. DOI: 10.1109/ICALT.2016.127.

[31] Paula Escudeiro, Nuno Escudeiro, Rosa Reis, Jorge Lopes, Marcelo Norberto, Ana Bela Baltasar, Maciel Barbosa, and José Bidarra. "Virtual sign–a real time bidirectional translator of portuguese sign language". In: *Procedia Computer Science* 67 (2015), pp. 252–262.

[32] Dhruva Bansal, Prerna Ravi, Matthew So, Pranay Agrawal, Ishan Chadha, Ganesh Murugappan, and Colby Duke. "CopyCat: Using Sign Language Recognition to Help Deaf Children Acquire Language Skills". In: *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. CHI EA '21. Yokohama, Japan: Association for Computing Machinery, 2021. ISBN: 9781450380959. DOI: 10.1145/3411763.3451523. URL: https://doi.org/10.1145/3411763.3451523.

[33] Nisreen Hassanain and Samer Al Moubayed. "Towards Empowering Deaf Sign Language Users: A Survey of Sign Language Recognition and Translation Systems". In: *Proceedings of the 1st International Workshop on Automatic Sign Language Translation*. ASLT '20. 2020, pp. 1–6. DOI: 10.1145/3334480.3381053.

[34] Microsoft Research. "Building a Scalable, Low-cost System for Automatic Sign Language Recognition and Translation". In: (2019). Accessed on May 4, 2023.

[35] Advaith Sridhar, Rohith Gandhi Ganesan, Pratyush Kumar, and Mitesh Khapra. "INCLUDE: A Large Scale Dataset for Indian Sign Language Recognition". In: *Proceedings of the 28th ACM International Conference on Multimedia*. MM '20. Seattle, WA, USA: Association for Computing Machinery, 2020, pp. 1366–1375. ISBN: 9781450379885. DOI: 10.1145/3394171.3413528. URL: https://doi.org/10.1145/3394171.3413528.

[36] Prem Selvaraj, Gokul N. C., Pratyush Kumar, and Mitesh M. Khapra. "OpenHands: Making Sign Language Recognition Accessible with Pose-based Pretrained Models across Languages". In: *CoRR* abs/2110.05877 (2021). arXiv: 2110.05877. URL: https://arxiv.org/abs/2110.05877.

[37] Vassilis Athitsos, Carol Neidle, Stan Sclaroff, Joan Nash, Alexandra Stefan, Quan Yuan, and Ashwin Thangali. "The American Sign Language Lexicon Video Dataset". In: *2008 IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*. 2008, pp. 1–8. DOI: 10.1109/CVPRW.2008.4563181.

[38] Morteza Zahedi, Daniel Keysers, Thomas Deselaers, and Hermann Ney. "Combination of Tangent Distance and an Image Distortion Model for Appearance-Based Sign Language Recognition". In: *DAGM-Symposium*. Springer. 2005, pp. 401–408.

 ©International Telecommunication Union, 2023

[39] Oscar Koller, Jens Forster, and Hermann Ney. "Continuous sign language recognition: Towards large vocabulary statistical recognition systems handling multiple signers". In: *Computer Vision and Image Understanding* 141 (2015). Pose Gesture, pp. 108–125. ISSN: 1077-3142. DOI: https://doi.org/10.1016/j.cviu.2015.09.013. URL: https://www.sciencedirect.com/science/article/pii/S1077314215002088.

[40] Alf Inge Wang and Rabail Tahir. "The effect of using Kahoot! for learning – A literature review". In: *Computers & Education* 149 (2020), p. 103818. ISSN: 0360-1315. DOI: https://doi.org/10.1016/j.compedu.2020.103818. URL: https://www.sciencedirect.com/science/article/pii/S0360131520300208.

[41] Alf Inge Wang. "Dozens of studies show learning benefits of using Kahoot!" en. In: (July 2020). URL: https://kahoot.com/blog/2020/07/01/dozens-of-studies-show-learning-benefits-of-kahoot/.

[42] "Open Trivia DB: Free to use, user-contributed trivia question database." In: *OpenTriviaDB* (Feb. 2023). URL: https://opentdb.com/.

[43] *ITU-T Work Programme*. Accessed: 2023-11-07. 2020. URL: https://www.itu.int/ITU-T/workprog/wp_item.aspx?isn=16868.

[44] *ISO/IEC 24756:2009, Information technology — Generic applications — Framework for specifying a common access profile (CAP) of needs and capabilities of users, systems, and their environments*. Accessed: 2023-11-07. 2009. URL: https://www.iso.org/standard/41526.html.

[45] David Fourney. *Using a Common Accessibility Profile to Improve Accessibility*. Accessed: 2023-11-07. Nov. 2007. URL: https://www.sigaccess.org/2007/11/using-a-common-accessibility-profile-to-improve-accessibility/.

[46] Pradipta Biswas. *Common User Profile Format*. Accessed: 2023-11-07. 2020. URL: https://www.itu.int/en/irg/ava/Documents/20200715IRG-AVA%20webinar/PB_WSISForum2020.pdf?csf=1&e=2lWd1p.

[47] R Burke Johnson, Anthony J Onwuegbuzie, and Lisa A Turner. "Toward a definition of mixed methods research". In: *Journal of mixed methods research* 1.2 (2007), pp. 112–133.

[48] Franz Dotter. "English for deaf sign language users: Still a challenge". In: *English in international deaf communication* (2008), pp. 97–121.

[49] William J. Frawley. "Sign Language Linguistics". In: *International Encyclopedia of Linguistics*. Ed. by William J. Frawley. 2nd ed. Vol. 1. Oxford: Oxford University Press, 2003, pp. 53–55.

[50] Wikipedia contributors. "Indo-Pakistani Sign Language". In: (Mar. 2023). Accessed on 4 May 2023.

[51] Ulrike Zeshan, Madan N Vasishta, and Meher Sethna. "Implementation of Indian Sign Language in educational settings". In: *Asia Pacific Disability Rehabilitation Journal* 16.1 (2005), pp. 16–40.

[52] "Alipur Sign Language". In: *Wikipedia* (Feb. 2023). URL: https://en.wikipedia.org/wiki/Alipur_Sign_Language.

[53] Heinrich Söbke. "Space for seriousness? Player behavior and motivation in quiz apps". In: *Entertainment Computing-ICEC 2015: 14th International Conference, ICEC 2015, Trondheim, Norway, September 29-Ocotober 2, 2015, Proceedings 14*. Springer. 2015, pp. 482–489.

[54] Isaac Cheah, Anwar Sadat Shimul, and Ian Phau. "Motivations of playing digital games: A review and research agenda". In: *Psychology & Marketing* 39.5 (2022), pp. 937–950.

[55] Melawati Kurnia, Maya Rahmawati, and Wahyudin Fitriyana. "Playing e-quizzes with KAHOOT!: Students' behavioral engagament on reading comprehension through KAHOOT!" In: *English Ideas: Journal of English Language Education* 1.1 (2020).

[56] Juan C Burguillo. "Using game theory and competition-based learning to stimulate student motivation and performance". In: *Computers & education* 55.2 (2010), pp. 566–575.

[57] Nergiz Ercil Cagiltay, Erol Ozcelik, and Nese Sahin Ozcelik. "The effect of competition on learning in games". In: *Computers & Education* 87 (2015), pp. 35–41.

[58] Hercy N.H. Cheng, Winston M.C. Wu, Calvin C.Y. Liao, and Tak Wai Chan. "Equal opportunity tactic: Redesigning and applying competition games in classrooms". In: *Computers and Education* 53.3 (Nov. 2009), pp. 866–876. ISSN: 0360-1315. DOI: 10.1016/j.compedu.2009.05.006.

[59] Maureen Wu, Calvin CY Liao, Zhi-Hong Chen, and Tak-Wai Chan. "Designing a competitive game for promoting students' effort-making behavior by virtual pets". In: *2010 Third IEEE International Conference on Digital Game and Intelligent Toy Enhanced Learning*. IEEE. 2010, pp. 234–236.

[60] Karin Van Es. "YouTube's operational logic:"The view" as pervasive category". In: *Television & new media* 21.3 (2020), pp. 223–239.

[61] Tatsuya Nakata. "DOES REPEATED PRACTICE MAKE PERFECT? THE EFFECTS OF WITHIN-SESSION REPEATED RETRIEVAL ON SECOND LANGUAGE VOCABULARY LEARNING". In: *Studies in Second Language Acquisition* 39.4 (2017), pp. 653–679. DOI: 10.1017/S0272263116000280.

©International Telecommunication Union, 2023

[62] Prem Selvaraj, Gokul Nc, Pratyush Kumar, and Mitesh Khapra. "OpenHands: Making sign language recognition accessible with pose-based pretrained models across languages". In: *arXiv preprint arXiv:2110.05877* (2021).

[63] John Brooke. "SUS: A quick and dirty usability scale". In: *Usability Eval. Ind.* 189 (Nov. 1995).

[64] Fred Davis and Fred Davis. "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology". In: *MIS Quarterly* 13 (Sept. 1989), pp. 319–. DOI: 10.2307/249008.

AUTHORS

Roshni Poddar is a research fellow at Microsoft Research Lab India (MSRI). She received her undergraduate degree in Computer Science and Engineering from PES University, Bangalore, India. Her passion lies in co-designing, building, and evaluating systems to facilitate learning through play with people from disability communities.

Pradyumna YM is a master's student at University of Tübingen. He was a research fellow at Microsoft Research Lab India (MSRI). He received his undergraduate degree in Computer Science and Engineering from PES University, Bangalore, India.

Divya Prabha Jayakumar is a multidisciplinary designer currently pursuing a master in Service Design at the University of Arts, London. She leverages design thinking and ethnographic research to create impactful experiences. In her previous role at Microsoft Research in India, Divya designed interventions empowering the visually impaired and deaf communities to leverage their skills through play. Driven by a passion for continuous learning, her keen interest lies in social innovation, inclusivity and system thinking.

Tarini Naik is a research fellow at Microsoft Research Lab India (MSRI). She received her undergraduate degree in Industrial Design from Srishti Manipal Institute of Art, Design and Technology, Bangalore, India. Her passion lies in product and user experience design, where she consistently incorporates system thinking into her design process. Her research interests are deeply rooted in accessibility and societal impact.

Punyat Tripathi graduated with a B.Sc. in Computer Science from National Institute of Speech and Hearing, Trivandrum, India. He is passionate about programming, emphasizing the application of strong technical skills to innovative projects. His interests include playing football, organizing events, photography, and traveling.

Nabeel TP graduated with a B.Sc. in Computer Science from National Institute of Speech and Hearing, Trivandrum, India. He is currently exploring professional opportunities that leverage my skills. His hobbies include learning more about animals and fact-checking viral videos.

Hemanth Reddy Yeddula completed his graduation in B.Sc. Computer Science from National Institute of Speech and Hearing, Trivandrum, India. He is passionate about creating videos using Adobe software for his YouTube channel. Additionally, he enjoys playing cricket, riding, travelling, gaming, and reading about politics.

Pratyush Kumar is an adjunct professor at Indian Institute of Technology, Madras.

Mohit Jain is a principal researcher at Microsoft Research Lab India (MSRI). He received his PhD in Computer Science & Engineering from the University of Washington, and a Master's in Computer Science from the University of Toronto. While pursuing his Ph.D., he also worked as a senior research engineer at IBM Research. His research interests are in healthcare, accessibility, and in general, global development. He has been working in these domains for more than a decade, and regularly serve on the technical program committees and organizing committees for prestigious conferences such as CHI, IMWUT/UbiComp, CSCW, and IUI.

Manohar Swaminathan is a senior principal researcher at Microsoft Research Lab India (MSRI) with a focus on accessibility solutions, primarily for children with vision impairments. He was at various times a professor at the Indian Institute of Science, Bangalore, a technology entrepreneur, and an angel investor.

 ©International Telecommunication Union, 2023