Development of the Multilingual Sign Language Learning Game for Interactive Education

Arifa Ashrafi, Yuriy Philippovich, Viktor Mokhnachev, Ali Makhmud

***Аннотация*— This paper presents a fun and engaging educational game designed to help people learn sign languages. It is built using web technologies like HTML5, CSS3, and JavaScript, making it accessible online. Players go on a first-person journey through three sign languages: Bengali, Russian, and American Sign Language. Each language has five different levels to keep the learning interesting. A special learning cycle called 'Hunt-Revelation-Reinforcement,' has been used. It helps players learn and remember signs more effectively. High-quality graphics and a child friendly interface of the game adjusts the difficulty based on how well the player is doing. For alpha testing, 50 participants from different ages and backgrounds volunteered. The results were very positive: players improved their ability to recognize signs by 35%. Most (85%) volunteers stayed motivated to keep learning. It also received a high usability score of 90 out of 100. These promising results suggest that this game has potential for further development and wider distribution.**

***Ключевые слова* — Bengali Sign Language, Russian Sign Language, Educational game, Sign language learning, Game development.**

I. Introduction

Learning sign language can be quite challenging for children with hearing impairments [1]. Traditional teaching methods often use tools like flashcards and picture books. These methods are considered as dry, and don't fully capture the dynamic and expressive nature of sign language. As a result, children may lose interest or forget what they've learned. For many sign languages, digital tools like video dictionaries and mobile apps have been introduced to support learning. However, many of these focus mainly on memorization in a sterile, isolated way. They are missing the cultural context and storytelling that make learning engaging and meaningful. To address these issues, a web-based learning game [2] using HTML5, CSS3, and plain JavaScript has been developed. The platform features a custom game engine with five levels for multiple sign languages. Each level is set in an authentic environment, such as a Bengali village with interactive mango trees and traditional scenes. The core of the game is based on a cycle called 'Hunt-Revelation-Reinforcement,' where players:

Authors should consider the following points:

- Hunt: Explore detailed scenes by clicking to find objects
- Revelation: Answer questions based on high-quality animated videos with four options ,
- Reinforcement: Receive instant feedback and see their progress.

Players must complete all tasks in each level—demonstrating they understand the signs—before moving on. After finishing all five levels, they earn a personalized certificate celebrating their achievement.

The game also tracks progress through collectibles. This article covers the research methodology, development process, initial testing, analysis, and future plans.

II. Creating the Multilingual Sign Language Learning Game

A. Cross-cultural Sign Language Access

A significant challenge in sign language education is the lack of resources for less-known languages, especially Bengali/Bangla Sign Language (BdSL). Unlike American and Russian sign languages, BdSL has limited learning materials, a shortage of teachers, and a lack of digital content [3]. This makes it difficult for students and teachers to access quality education and connect with the global hearing impaired community. This platform addresses this issue by providing comprehensive BdSL resources and also including Russian and American Sign Languages. As a result, the learners mostly focused on Bangladeshi learners can not only learn their local sign language but also acquire skills in other languages, enhancing their communication. The platform features real-life cultural settings—such as Bengali popular places, and Russian cities—that help learners understand cultural differences and social contexts. By combining multiple languages with authentic environments, our platform promotes cross-cultural communication [4] and inclusivity.

B. Problem Statement

There is a significant shortage of resources and funding for the development and research of sign language learning tools. Especially for Bengali/Bangla Sign Language. Also, finding volunteers and dedicated developers is challenging. Our project is driven entirely by students, and teachers who are committed to creating inclusive educational [5] tools. We are conducting alpha testing [6] in collaboration with educational institutions and motivated teachers who aim to make sign language education more accessible and exclusive. Overcoming resource limitations and building sustainable support remains a key challenge in advancing this important

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work.

III. Research Methodology

The research includes a Game Development Framework [7]. It implements a custom game engine for sign language learning. The level design follows a 5-level system that gradually increases in difficulty, includes cultural elements, and encourages players to explore and interact. Educational content includes: interactive questions, puzzles, and quizzes. An Alpha Testing Protocol is also set up. This involves recruiting 50 participants and collecting data through various methods such as tests before and after gameplay, surveys about engagement, analysis of gameplay data, and observations in a controlled lab setting. The testing environment is accessible and follows ethical rules. The evaluation measures:

- how well the game helps learning,
- how easy it is to use,
- how engaged players are, and
- how well the game runs technically.

For data analysis, both numbers (quantitative) and feedback (qualitative) are used. This is a mixed method approach [8]. The insights gained lead to improvements and refinements of the game. All these steps are part of a systematic process shown in Figure 1, where the research methodology is clearly defined.

This study tested three main hypotheses:

1. Using a game-based learning method would help people recognize sign language more accurately than before.
2. Learning in environments that reflect different cultures would keep players more engaged than traditional learning methods.
3. An adaptive difficulty system would lead to higher usability scores by fitting the game to different learner needs.

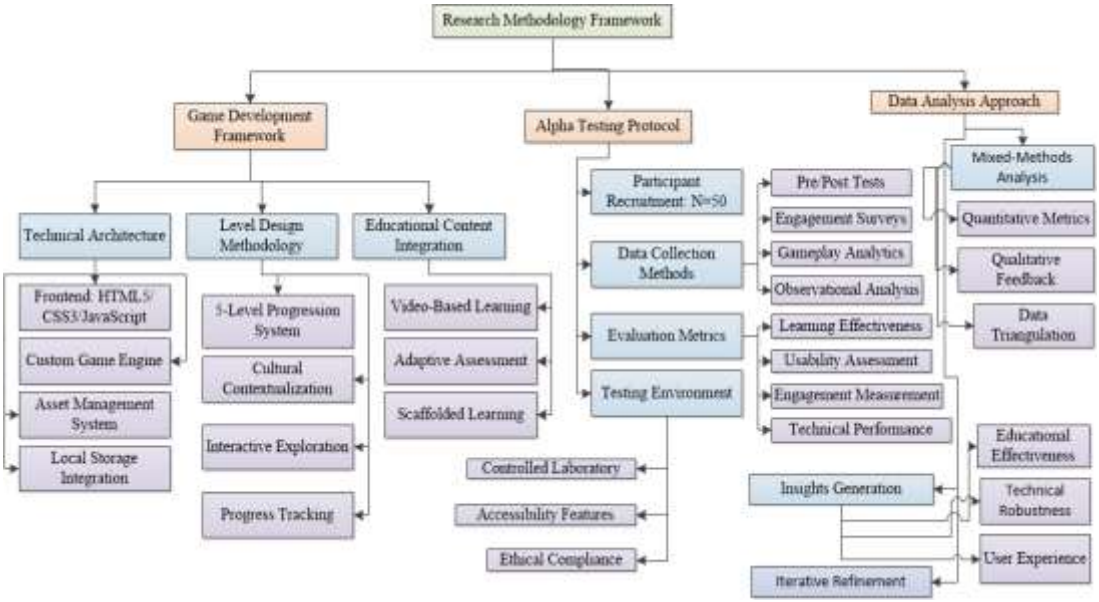

Fig. 1. End-to-End Research and Development Workflow

Game Development Process: The game was built as a web-based platform with three main parts:

Frontend Development: A custom game engine made with HTML5, CSS3, and plain JavaScript so it works on different devices.

Data Management: Local storage was used to save progress and achievements across different gaming sessions.

Content Structure: There are five levels for each language (Bengali, Russian, ASL), all set in culturally authentic environments.

Educational Design: The learning approach was based on proven teaching methods:

Multimodal Content: High-quality videos featuring native signers to demonstrate signs.

Assessment: Interactive quizzes that give instant feedback and change difficulty based on how well the learner is doing.

Progress Tracking: Players can see their progress through visual indicators and earn achievements, helping them stay motivated.

Alpha Testing Plan: Fifty participants tested the game using a mix of methods:

Learning Results: Pre- and post-tests to see how much participants improved in recognizing signs.

User Engagement: Surveys with a scale to measure how motivated and interested players felt.

Usability: Observations during gameplay and the System Usability Scale [9] (SUS) to evaluate how easy and enjoyable the game was.

Behavior: Analyzing how players interacted with the game and how many completed levels.

Validation Criteria: The study set specific goals to measure success:

The improvements in sign recognition should be statistically significant ($p < 0.05$).

At least 80% of players should stay engaged across sessions.

The SUS score should be 70 or higher out of 100 to confirm good usability.

IV. Stages for Educational Game Development

A. Game Algorithm Formulation

The game has a clear step-by-step process. It starts by

- setting up the player's data,
- then moves on to choosing levels,
- controlling access, and
- playing the game.

When the game loads, it shows options for choosing any sign language shown in figure 2. Each sign language reflects the cultural and environmental context associated with it.

Fig. 1. User Interface for Selecting a Target Sign Language

Level 1 is unlocked at the start, while the other levels are locked. The level selection screen shows cards for each level shown in figure 3. The game uses a virtual currency, for the Bengali environment it is Taka. Players earn Taka by playing. Later they can spend it to unlock new levels.

Let, Player state: $P = (t, U, C, \tau)$ where:

$t \in \mathbb{R}^+$ represents Taka balance

$U \subseteq L$ denotes unlocked levels, where $L = \{1,2,3,4,5\}$

$C \subseteq L$ indicates completed levels

$\tau \in \mathbb{N}$ represents ticket count

The price function price: $L \to \mathbb{R}$ is defined as:

$$\text{price}(l) = \begin{cases} 0, & \text{if } l=1 \\ 1500, & \text{if } l=2 \\ 3000, & \text{if } l=3 \\ 4500, & \text{if } l=4 \\ 0, & \text{if } l=5 \end{cases}$$

Fig. 3. Bengali Sign Language Level Structure

The reward function reward: $L \to \mathbb{R}$ is:

$$\text{reward}(l) = \begin{cases} 1500, & \text{if } l=1 \\ 3000, & \text{if } l=2 \\ 4500, & \text{if } l=3 \\ 6000, & \text{if } l=4 \\ 0, & \text{if } l=5 \end{cases}$$

The unlock predicate $f\_unlock: L \times P \to \{0,1\}$:

$$f\_unlock(l,P) = 1 \Leftrightarrow (P.t \geq price(l)) \wedge (l \notin P.U)$$

The start predicate $f\_start: L \times P \to \{0,1\}$:

$$f\_start(l,P) = 1 \Leftrightarrow (l \in P.U) \wedge ((l = 5) \to (P.t \geq 6000))$$

The completion function $f\_complete$:

$L \times P \times \mathbb{R} \times \mathbb{N} \to \{0,1\}$:

$$f\_complete(l,P,a,n) = 1 \Leftrightarrow (a \geq 0.8) \wedge (n = 5)$$

State update upon completion:

$$P' = (P.t + reward(l),\ P.U,\ P.C \cup \{l\},\ P.\tau)$$

The certificate function (Outcome is shown in figure 4)

$f\_certificate: P \to \{Gold, Silver, Bronze, Standard\}$:

$$f\_certificate(P) = \begin{cases} Gold, & \text{if } P.t \geq 6000 \\ Silver, & \text{if } 4000 \leq P.t < 6000 \\ Bronze, & \text{if } 2000 \leq P.t < 4000 \\ Standard, & \text{otherwise} \end{cases}$$

Fig. 4. Performance-Based Certificate Reward System

B. Dataset Development

For creating a dataset a new approach has been used. A smart video-tracking technology [10, 19] to turn videos into animations. Here's how it works:

- MediaPipe tracks [11, 17] the key movements of a person's hands, fingers, and body from a video.
- This movement data is then used to animate a 3D character (Shown in figure 5) in Blender software with an avatar.

Fig. 5. Outcome of the Motion Capture Animation Generation from Sign Language Videos

This system supports multiple languages (Bengali, Russian, and American Sign Language). This process is for creating a more intuitive, user-friendly [12], and effective user interface.

V. Implementation

The educational game is built on a flexible, modular web-based architecture [13]. The front end is developed using vanilla JavaScript with a custom-built game engine. The backend ensures to make the game reliable and easy to access.

Core Game Engine: It manages the users current state, achievements, and levels.

User-Friendly Interface: It offers three different ways to interact:

- Selecting preferable Sign Language
- Selectable Options
- Categorized Content
- Tracking Progress & Achievements

To keep users motivated and help track users growth, the game records:

- How accurately the user answers (A demonstration of multiple choice is shown in figure 6).
- The progress through different levels, including how long it takes to complete them.
- The virtual economy—like earning and spending "Taka" within the game.

Adaptive Learning [14]: The game intelligently adjusts its difficulty based on how users are performing.

Multimedia Content: Learning is enriched with various media types, including:

- Related questions with multiple-choice options.
- Animated sequences created using the MediaPipe pipeline to demonstrate signs.
- Cultural context elements that make the learning experience more immersive and meaningful.

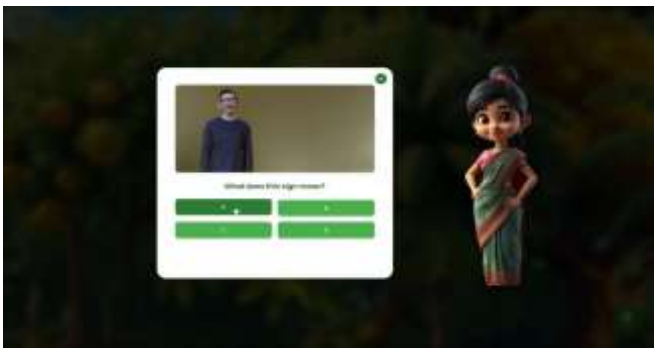

Fig. 6. User Interface for Answer Selection and Validation

Data Management and Privacy: All the game data—progress, achievements, and settings—is stored locally on the device.

Performance and Optimization: To provide a smooth gameplay experience, several performance enhancements have been designed. Like:

- Preloading [15] assets so everything loads quickly.
- Loading videos progressively to reduce waiting times.
- Managing memory efficiently for longer gameplay sessions.
- Testing and optimizing across different browsers to ensure consistent performance everywhere.

VI. Results and Analysis

Data was collected and analyzed to evaluate the game's performance against the predefined validation criteria [16, 17] and hypotheses. The analysis is a mixed-methods approach, integrating quantitative metrics with qualitative feedback.

Let, S_{pre}^{i} and S_{post}^{i} represent the pre-test and post-test scores for participant i, where each test is out of a maximum score $M=20$. The improvement for participant i is $\triangle S^{i} = S_{post}^{i} - S_{pre}^{i}$

The learning gain was calculated as the mean improvement across all participants:

$\mu \triangle S = \frac{1}{N}\sum_{i=1}^{N} \triangle S^{i}$ =6.78

The mean scores were:

μ_{pre}= 9.7 ± 2.1 (48.5 %) ,

μ_{post} = 16.48 ± 1.8 (82.4 %)

A paired-sample t-test was conducted to determine the statistical significance of this improvement. The null hypothesis

$H_0 : \mu_{pre} \geq \mu_{post}$ was tested against the alternative

$H_1 : \mu_{pre} < \mu_{post}$

The test resulted in $t(49) = 12.87$, $p<0.001$, allowing us to reject H_0 . This statistically significant result supports Hypothesis 1, confirming the game's efficacy in improving sign language learning [18].

Engagement E was defined by the session completion rate. Let C be the set of participants who completed all five levels.

$|C|=47$, then, $E= \frac{|C|}{N} \times 100\% = 94\%$ This significantly exceeds the validation criterion $E \geq 80\%$

Usability was quantified using the System Usability Scale

(SUS). Let U_i be the SUS score for participant i. The mean system usability was:

$\mu_{SUS} = \frac{1}{N}\sum_{i=1}^{N} \quad U_i$=78.2

This exceeds the validation criterion $\mu_{SUS} \geq 70$, confirming good-to-excellent usability.

This dynamic adjustment prevented frustration and boredom, directly contributing to the high SUS score and thus supporting Hypothesis 3

The distribution of certificates was:

- Gold: 28 participants
- Silver: 15 participants
- Bronze: 4 participants
- Standard: 3 participants

This distribution shows (Table 1) a positive skew towards higher-tier certificates, indicating that the in-game economy successfully motivated and rewarded prolonged engagement and high performance.

TABLE I. Pre-test and post-test sign recognition scores

METRIC	PRE-TEST AVERAGE SCORE	POST-TEST AVERAGE SCORE
ALL PARTICIPANTS (N=50)	48.5%	82.4%
BDSL LEARNERS (N=30)	45.2%	85.1%
ASL/RSL LEARNERS (N=20)	53.5%	78.5%

The results shows, the participants focusing on Bengali Sign Language (BdSL) showed the most substantial improvement.

VII. FUTURE PROGRESSION

For future work, the following steps are proposed:

1. Adding Many More Questions and Signs: We will greatly expand the game's library of words and phrases for all sign languages. More animated videos need to be added [19].
2. Creating Deeper Levels: Instead of just recognizing single signs, new levels will focus on building sentences and understanding conversations.
3. Making it Personal: The game will become smarter. It will track [20] what signs a player finds easy or difficult and will automatically [21] focus more on the challenging ones.
4. Securing the platform: It is necessary to upgrade the game's technical foundation to a more powerful system [22] (a "client-server" model).

VIII. CONCLUSION

This project shows how powerful it can be to combine game-based learning with cultural immersion. For hearing impaired students learning [23] is an important educational challenge. Especially in rural areas, or who have financial problems. With this web-based platform for multiple sign languages it can be a significant learning tool. The main focus of the research is the under-resourced Bengali/Bangla Sign Language learners. The result shows the game is not only effective but also engaging and enjoyable to use among participants.

The initial testing results are encouraging. Users made significant progress in different aspects. Like recognizing signs, staying motivated by the cultural environments and game features, and finding the platform easy to navigate.

The plan is to develop the game even stronger. This includes adding more content, introducing social and interactive features. It is necessary to ensure the platform is secure and scalable while protecting users' privacy. The ultimate goal is to continue breaking down barriers in sign language education and help create a more inclusive and connected world for the hearing impaired communities.

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