We Play and Learn Rhythmically: Gesture-based Rhythm Game for Children with Intellectual Developmental Disabilities to Learn Manual Sign

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ABSTRACT

Manual sign systems have been introduced to improve the communication of children with intellectual developmental disabilities (IDD). Due to the lack of learning support tools, teachers face many practical challenges in teaching manual sign to children, such as low attention span and the need for persistent intervention. To address these issues, we collaborated with teachers to develop the Sondam Rhythm Game, a gesture-based rhythm game that assists in teaching manual sign language, and ran a four-week empirical study with five teachers and eight children with IDD. Based on video annotation and post-hoc interviews, our game-based learning approach has the potential to be effective at teaching manual sign to children with IDD. Our approach improved children attention span and motivation while also increasing the number of voluntary gestures made without the need for prompting. Other practical issues and learning challenges were also uncovered to improve teaching paradigms for children with IDD.

CCS CONCEPTS

• **Applied computing → Education**; • **Social and professional topics → People with disabilities**.

KEYWORDS

Children with intellectual and developmental disabilities, Manual sign learning, Gamification, Rhythm game

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1 INTRODUCTION

Communication deficiencies are a core symptom of intellectual developmental disabilities (IDD) [8, 40, 59]. To overcome these deficiencies, unaided augmentative and alternative communication (AAC) systems, such as manual sign systems, assist children with IDD to produce functional speech [6, 13, 18, 24, 50, 56]. Manual sign systems, such as Sondam [34], Makaton [26], Baby Sign [25], Signalong [54], and Guk-System [1, 21], characterized by body movement communication methods paired with speech, have been used to teach communication and language skills. Despite the potential of manual sign systems, there is a lack of research and consensus on best practices for manual sign education methodologies.

Teaching a manual sign system through traditional methods, such as books, has its limitations. Children with IDD usually have a short attention span due to a lack of motivation and interest in learning [2, 3, 51, 52, 62, 64]. They quickly tire of repetitive or complex tasks and face disruptions in learning, thus often taking longer to learn. Children with IDD also have some visual perception issues; not all sign elements can be accurately represented using static images or text descriptions, and thus they have difficulty organizing, interpreting, and recalling static images [31, 33, 39, 57]. Overall, independent learning is difficult and they require more caregiver intervention during the learning process. These learning difficulties for children with IDD have increased the usage and prevalence of

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the manual sign system. In order to accelerate the adoption and usability of manual sign, best practice teaching methods must be established through extensive qualitative and quantitative analysis that directly address the current challenges of learning for children with IDD.

In this paper, we identified three main challenges for children with IDD when learning the manual sign system: 1) attention span, 2) gesture imitation, and 3) memorization and habituation. To address these issues, we propose the Sondam Rhythm Game, a gamified learning system that teaches the Korean manual sign system Sondam to the rhythm of children's songs. We conceptualized the elements of the rhythm game to optimally teach gestures based on the input of literature reviews and expert group interviews. To evaluate our game's potential and limitations compared to traditional online learning, we ran a four-week deployment study with five teachers and eight children with IDD. From the evaluation, we demonstrated that the Sondam Rhythm Game increases learning motivation and improves the imitation of gestures for children with IDD.

This study offers three significant contributions as follows:

- Identification of the practical barriers for teaching a manual sign system and conceptualization of a manual sign learning methodology for children with IDD based on expert group interviews and professional feedback.
- To the best of our knowledge, there is no manual sign learning game software for children. We validated the potential benefits of the Sondam Rhythm Game through a direct comparative analysis vs. a traditional video-based learning method.
- Our manual sign learning system was deployed in a real classroom environment and applied by teachers for children with IDD.

2 BACKGROUND WORK

2.1 Manual Sign Communication for Children with IDD

The ability of children with IDD to express their ideas to others is a crucial prerequisite to adjusting to society and growing into independent human beings [35, 53]. Unaided and aided augmentative and alternative communication (AAC) systems are continually being developed and disseminated [13, 18, 24, 44, 50, 56], and manual sign systems have been specially considered as an alternative for children who have difficulty using spoken or tool-aided AAC. The manual sign system designed for the children contains simplified movements with simple hand expressions that are less abstract or complex than traditional sign language for the deaf [6, 63]. The manual sign system can be used as a complementary form of communication for children with IDD. It can also improve general language skills, such as vocabulary, for the early education of developmentally typical infants [1, 21, 25, 26, 34]. The Guk-System was developed as an early assistance communication method for children with Down's syndrome who have difficulty speaking; it is now a standard communication method for people with moderate intellectual disabilities [1, 21]. Makaton and Signalong are simplified British sign language systems. Both have proven to be effective for children and adults with developmental disabilities, such as autism sensory disorders [22]. The Korean manual sign system Sondam [34] was developed specifically to promote the communicative abilities of children with IDD. Such manual sign systems take a relatively long time to learn and become a practical method of communication [41, 49]. Many studies have investigated the efficacy of manual signs, such as Sondam, for their improvement of communication, but studies on best practices and teaching paradigms are lacking.

2.2 Approaches Employed to Supplement the Learning of Children with IDD

2.2.1 Supplementing Learning by using Music. In general, people with IDD acquire languages through repetitive practice paired with specific words and visual cues due to slow learning and limited memory ability [17, 19, 20, 44]. Teachers may teach by vocalizing the word 'snack' while presenting a physical snack. Contrary to simple repetitive learning using images or text that may induce boredom, music is a potential medium for improving the recall of language with more engagement [7, 11, 15, 27, 55]. Buday [11] proved that music positively impacted a child's concentration, ability to accurately imitate manual sign, and increased short-term memory of children with IDD. Simpson *et al.* [55] used familiar songs to teach animal symbols to study participants (3–5 years old) with higher response rates from participants in musical conditions than those in non-musical conditions. Moreover, evidence indicates that children with IDD enjoy musical activities [27], and that music can mitigate some behavioral, emotional, sensory, and motor difficulties [7, 15].

2.2.2 Supplementing Learning by using Gamification. In recent years, gamification have been the most studied educational methodology from infants to adults [42]. This approach improves self-confidence and accelerates learning performance by improving learner attention and motivation [14, 16, 28, 29, 36, 37, 43, 45, 47, 48, 60, 61, 65]. Special education has also explored gamification to improve learning skills and communication skills for children with IDD [4, 5, 10, 23, 32, 42]. Brown *et al.* [10] proved that game-based learning improves children with IDD mathematical skills by increasing in-game scores. Since children with IDD have difficulty in learning due to their lack of attention, studies have been conducted to increase attentional skills through motion-based games. Kuswardhana *et al.* [32] developed a computer game that employs Kinect sensors to improve IDD children concentration. Bartoli *et al.* [4] researched touchless motion-based gaming for autistic children. They observed that motion-based touchless games improved attention skills for autistic children. An exercise-based game was used to improve the memory and physical movement of children with IDD. An additional research goal of these studies is to enhance verbal/non-verbal communication skills for social activities. González-Ferreras *et al.* [23] verified that educational video games improved down syndrome children communication speech skills by increasing their motivation and engagement. Bernardini *et al.* [5] also presented a game in which children with autism improved social communication skills by interacting with a human-like virtual character, indicating that virtual characters or guides are an important variable for engagement. These works further validate

Table 1: A list of questions.

Session	Questions
Focus Group Interview	What is the current teaching method used for Sondam education? What were the difficulties and limitations of current Sondam education? What are the possibilities for and advantages of a game-based Sondam education system?
Image Board Activity	What elements should be considered when designing a game-based Sondam education system? Which type of game would you design to teach Sondam manual sign language?

that game-based learning is a reliable learning tool for children with IDD. Therefore, we set to validate gamification effectiveness when combined with manual sign learning for children with IDD.

3 PRELIMINARY STUDY

3.1 Procedural and Data Collection

In order to gain a better understanding of the current challenges of teaching the manual sign system to children with IDD, we conducted a workshop with six teachers (T1-T6). They are experienced teachers from local special education schools who teach children aged 3 to 13 years and expressed interest in teaching manual sign to children with IDD. T1-T4 had more than a year of experience in manual sign, while the others (T5, T6) had less than 6 months of experience. The workshop was conducted via Zoom video meetings and lasted 2.5 hours: 1) Focus group interviews to discuss the current challenges of the existing teaching methods and the possibilities of game-based education tools for Sondam manual sign language and 2) an image board activity to design a game-based manual sign education system and conceptualize the Sondam Rhythm Game. The questions used in the workshop are shown in Table 1. With the teachers' consent, the workshop was recorded and transcribed.

3.2 Analysis and Findings

The recorded video resulted in a total of 40 pages of transcription. We followed Braun and Clarke's version of Thematic Analysis [9] to analyze our key focus on the challenges and needs of teaching the manual sign system and the possibility of a viable game-based education system. We attempted to achieve neutrality by coding interviews separately and discussing themes. Our thematic analysis yielded 14 sub-themes that coalesced into three key themes as follows.

3.2.1 Difficulties and limitations of existing Sondam teaching methods. Most teachers answered that when teaching manual sign to students, they use the standard Sondam teaching videos or student programs. (T2) "*I usually taught by presenting a video of previous children performing Sondam manual sign and showing it to the next class.*" However, there are several difficulties and limitations to this existing educational method. First, teachers have difficulty in teaching due to the short attention span and high level of distractibility of children with IDD, so they need methods that are dynamically challenging and engaging. (T3) "*Because their concentration is very short during the class, it is challenging for them to learn.*" (T4) "*It is not easy to sit them down and prepare for learning because they have difficulty in paying attention. Therefore, it takes a lot of time to start learning.*" Second, repetitive learning is essential because Sondam is a language, but existing educational methods are unable to improve students' lack of interest and motivation for repetitive learning. (T5) "*There are a lot of confusing aspects when using Sondam. So if a student learned a word yesterday, it needs to be repeated the following day. However, if teachers teach repetitively, children often don't like it and refuse education.*" (T2) "*It is challenging to integrate Sondam manual sign language into daily life or subject classes. In addition to classes, students have to repeat and learn, but they often get annoyed when teachers try to teach.*" Third, because of the greater difficulty of simple imitation learning for children with IDD, current learning materials, such as card symbols and video clips, have limitations when teaching manual sign. (T1) "*Children with IDD lack imitation skills, so they have difficulty in following gestures from a screen on their own. That's why a teacher's frequent intervention is needed.*" (T5) "*Repetitive learning is essential for children with IDD. But, becoming entirely reliant on teachers leads to becoming limited to one-on-one teaching.*" As repetitive gesture learning is required, teachers are faced with the burden of constant repetition, testing their patience and endurance. Fourth, children with IDD need to memorize and replicate manual signs in daily life, but the learning process of children with IDD is generally lengthy and challenging. (T4) "*It is tough to communicate with them because it may be difficult to understand a child's gesture.*" (T5) "*It is difficult for them to use words they learned during class in real life.*" (T6) "*Even though children can memorize gestures through traditional learning methods, they often have difficulty in using them on their own in everyday life*". In order to solve this problem, it is necessary to identify and establish best practice Sondam education methods that can be used in home, school, and daily life. Lastly, there is a lack of Sondam manual sign education tools, and there are limited ways to adjust to each individual student's disability characteristics and tendencies. (T4) "*Since individual characteristics are diverse, each child should have a personalized educational method, but I think there is still a lack of support tools to deal with the various characteristics of children with IDD*".

3.2.2 Potential of game-based Sondam learning support tools. Game-based education tools are widely used in children with disabilities because they provoke student interest and motivation, increasing attention. A game-based Sondam education system also has potential. First, children with IDD generally have high interest in media or games., which strengthens concentration and motivation in the learning process. (T1) "*Since most students are interested in media or games, a game-based system will likely be used as a form of learning reinforcement.*" Second, game-based learning support tools can induce voluntary student learning and facilitate repetitive learning. (T3) "*Children focus more on videos or songs they know than following teacher's instructions. I think games are a good way to improve focus for students.*" (T4) "*I think there will be many variable visual elements in the game, so it will be good for improving focus and learning repetitively.*" (T2) "*Children are more interested in characters than teachers, and they may be more immersed in learning.*" The advantage of this learning method is that it can reduce the burden of one-on-one education for teachers. Third, game-based education tools can be expanded as an option for home-based virtual learning. (T5) "*If this game can be used on computers or mobile devices, I am looking forward to using it for the school-home learning process and learning outside of school.*" (T6) "*Some apps use tablets during remote classes as communication aids, and children are not reluctant to use tablets, and such support apps were beneficial for virtual classes during the pandemic.*" We found that teachers prefer software applications that can be used on tablets and notebook devices, due to accessibility. Last, the above mentioned game-based educational tools can improve the students' learning experience and consequently increase learning performance.

3.2.3 Game strategies to enhance the effectiveness of Sondam learning. We derived three game strategies when designing the game-based application for manual sign language learning through the teacher workshop image board activities and sketch scenarios.

Design to increase motivation and attention span for Sondam learning The most crucial purpose of the game-based Sondam education system is to strengthen the learning motivation of children with IDD and improve their concentration during the learning process. To address this, the three teachers (T1, T3, T5) came up with ideas to maintain student interest and improve student concentration by using children's songs or characters from recognizable fairy tales, following the learners' preferences. Moreover, all teachers maintained that positive and immediate visual/audio feedback and rewards need to be administered. The final goal of this system is to elicit voluntary gesture imitation of children, creating a cycle of repetitive learning takes place naturally. (T1) "*A game in which children guess the correct answer card when presented a Sondam gesture card that also match the lyrics of a song. Most of the students respond positively to songs, and there are short words and repeated words in a single song, which is suitable for repetitive learning.*" Children with IDD are often motivated by music rather than conversation, and they learn words in a song through the melody and recall them naturally through daily repetition.

Design to improve recognition and imitation of gestures for Sondam learning Since manual signal language is a gesture, it is essential to imitate gestures through videos or teachers. However, due to the lack of imitation skills of children with IDD, it is challenging to imitate images or videos independently. To solve these difficulties, three teachers (T2, T4, T6) suggested imitation games through character or self-modeling, with clear gestures and guides. (T4) "*When a word is presented, student A sees it, gestures it to his friend B, and B guesses the answer. Alternatively, when a character expresses a gesture, the student guesses the word. Sondam is a sign language-like gesture, so there must be an element of inter-communication.*"

Design to enhance memorization and habituation of Sondam learning Since Sondam is a language developed for children with IDD who have difficulty communicating, there needs to be extra customization, guidance, and accessibility to Sondam learning to enhance memorization. Therefore, there is a need to increase the effectiveness of learning performance through preview functions or functions to control the difficulty and speed according to each student's abilities. In addition, this customization should be produced as a computer-based software application so that education can be conducted not only in classrooms but also at home to improve habituation.

4 IMPLEMENTATION OF THE SONDAM RHYTHM GAME

Based on feedback from the preliminary study, we designed the 'Sondam Rhythm Game,' a manual sign learning application using a children song imitation-based, positive-feedback mechanism game. The main goals of the Sondam Rhythm Game consisted of the following: 1) enhance motivation and concentration, 2) clear guidance to promote the imitation of gestures, and 3) improvement of memorization. In order to attract a child's motivation and attention, the game introduces the narrative theme of *The Little Prince fairy* tale due to relatability being important to maintain motivation. We improved relatability by selecting ten children's songs that were easy to sing and related to daily life. Each song included 5-10 words (gestures) frequently used in real life. Based on the feedback from teachers, a self-camera was applied to reflect the child's appearance for increased engagement (see Figure 1A). To provide guidance when performing gestures, a monkey character with long arms and human-like hands was presented to teach manual sign while singing a song. Visual feedback effects were added so that children could observe their success and gain confidence when performing gestures (see Figure 1D). Negative feedback expressions were replaced with more positive ones, regardless of whether the children made an incorrect gesture or not (*e.g.*, "cheer up!" instead of "missed"). We aimed to increase the frequency of positive responses and reduce frustration. As shown in Figure 1 (bottom left), a preview is presented before the game start to increase success rate for self-confidence by informing the students of learning goals in advance. The functions, such as game difficulty control, speed control, play/pause and camera on/off, were set by teachers or caregivers to each child's level. To incorporate a sense of accomplishment, a final score was included to reward the learner's efforts.

Figure 1 shows example scenes of our game system. Our game scenario is as follows. The first scene is the *Song Select* scene where a player (child) selects a planet (song). Next, the *Preview* Scene is the second scene in which the player can view a preview of which manual sign gesture to learn. The player can adjust the difficulty level of the game. The harder the difficulty, the more words to learn in a song. The third scene is the *Game Play* scene. The player must replicate an exact gesture according to the guide image and lyrics at the corresponding timing. If the player makes a correct gesture at the correct timing, a visual effect appears, and the player increases his/her score. The visual feedback and score vary according to timing accuracy. At the end of the game, the score and results are provided as feedback.

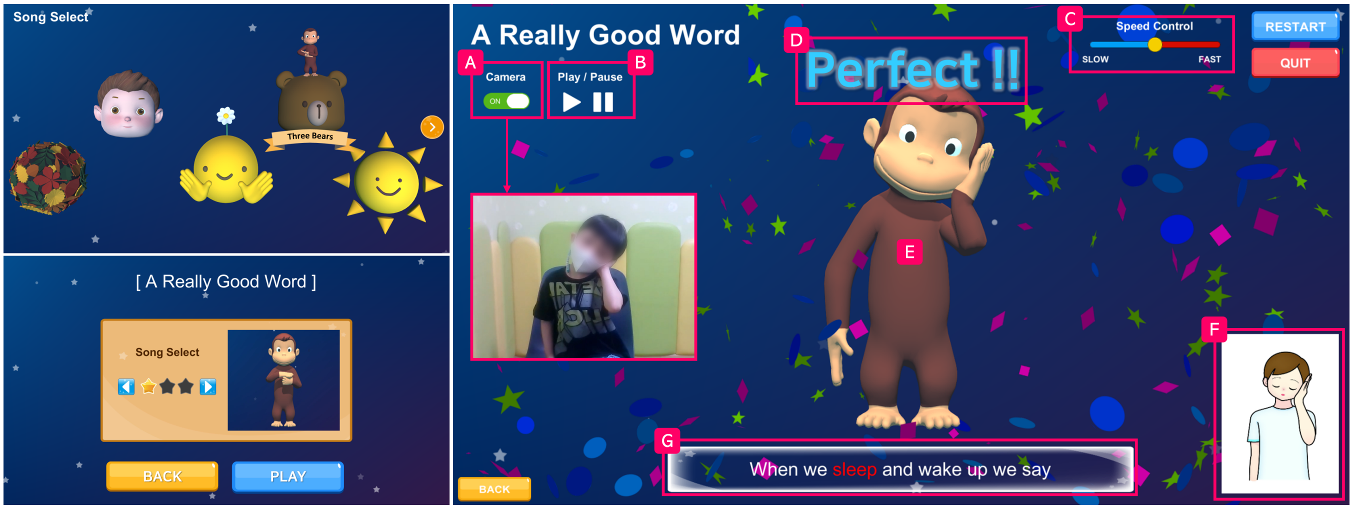


Figure 1: Examples of the game scene. *Song Select* (top left), *Preview* (bottom left), and *Game Play* (right). The Game Play scene involves the functions for the educational rhythm game: player camera (A), play/pause (B), speed control (C), visual feedback (D; perfect, excellent, good, and cheer up), lead character (E), guide image (F; the preview of what gestures to take at the timing), and lyrics (G; the gesture words are highlighted as red).

Table 2: Word sets used in the empirical study. Note that four out of the ten children songs in the game were used for this study.

Word set	Song title	Word
P1	Three Bears	dad, mom, baby, home
P2	The Greeting Song	teacher, friend, again, hello
P3	A Really Good Word	happy, love, family, sleep
P4	Banana Cha Cha	eat, share, together, beautiful

5 EMPIRICAL STUDY

In order to identify the efficacy of the Sondam Rhythm Game for manual sign learning of children with IDD, a comparative study was conducted: the traditional video-based learning method (**VL**) vs. our Sondam Rhythm Game method (**GL**). Four popular children's songs for the lower grades of elementary school, and 16 manual sign gestures (*i.e.*, words) to be learned were selected (see Table 2) and the level of difficulty between word sets was controlled by the evaluation of special education teachers. In the study, we randomly displayed feedback for the performance of gestures instead of using gesture recognition, which is to avoid the possible confounding factor of a machine learning-based gesture recognizer.

Initially, we recruited nine teachers (six of them participated in the preliminary study) and 12 students from local special education schools, aged between 4 and 12 years. The 12 students were divided into two groups, A and B. Group A was taught word set P1, P2 following VL and P3, P4 following GL. Group B was taught P3, P4 following VL and P1, P2 following GL. Unfortunately, 4 students out of 12 students were excluded in the middle of the experiment due to the COVID-19 restrictions. As a result, five teachers and eight students (six in Group-A and two in Group-B) completed the experiment. Note that the word set data collected was unbalanced due to excluded participants in Group A and B, but other factors, such as the order of learning methods and recall test were balanced. Because the difficulty between word sets was controlled, the exclusion of some data is not expected to have a major effect. The average age of the eight students was 9.3 (*SD*=1.71); four (C1, C3, C6, and C8) with intellectual disabilities, three (C2, C5, and C7) with Autism Spectrum Disorder (ASD), and one (C4) with Borderline Autism. To provide a familiar learning environment to each child, we ran a four-week deployment study remotely with the special education teacher and the child communicating one-on-one. We offered teachers a laptop with our game system pre-installed and a webcam device to record their student's behavior. We provided every teacher with a manual document explaining how to use the game and introduced the instructions of the experimental procedure and schedule as well.

During the experiment, teachers were asked to teach the Sondam manual sign system using the two methods (VL and GL) corresponding to each student's learning schedule as shown in Figure 2. A student learns one word set, *i.e.*, a few words in a song per day. In order to reduce the influence of teacher's individual teaching styles, we asked teachers to use the same teaching strategy for each of the two methods. In a session, teachers first prepared the learning method and word set. Then, they explained manual sign gestures corresponding to the word set to their student and demonstrated the gestures by themselves. After demonstrating, the teacher asked their student to imitate the manual sign gestures of the instructor in the video or the character in the game as shown in Figure 3. If the student is distracted, the teacher mediated their students by using verbal prompts and physical prompts. A verbal prompt is a teaching method that encourages learners to perform tasks by speaking directly, such as "look at it" and "let's do this." A physical prompt mediates learners to make a correct gesture through

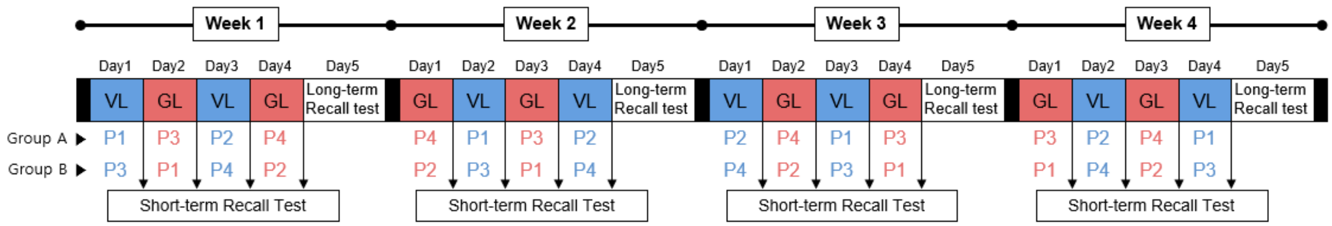


Figure 2: Learning schedule for the deployment study.

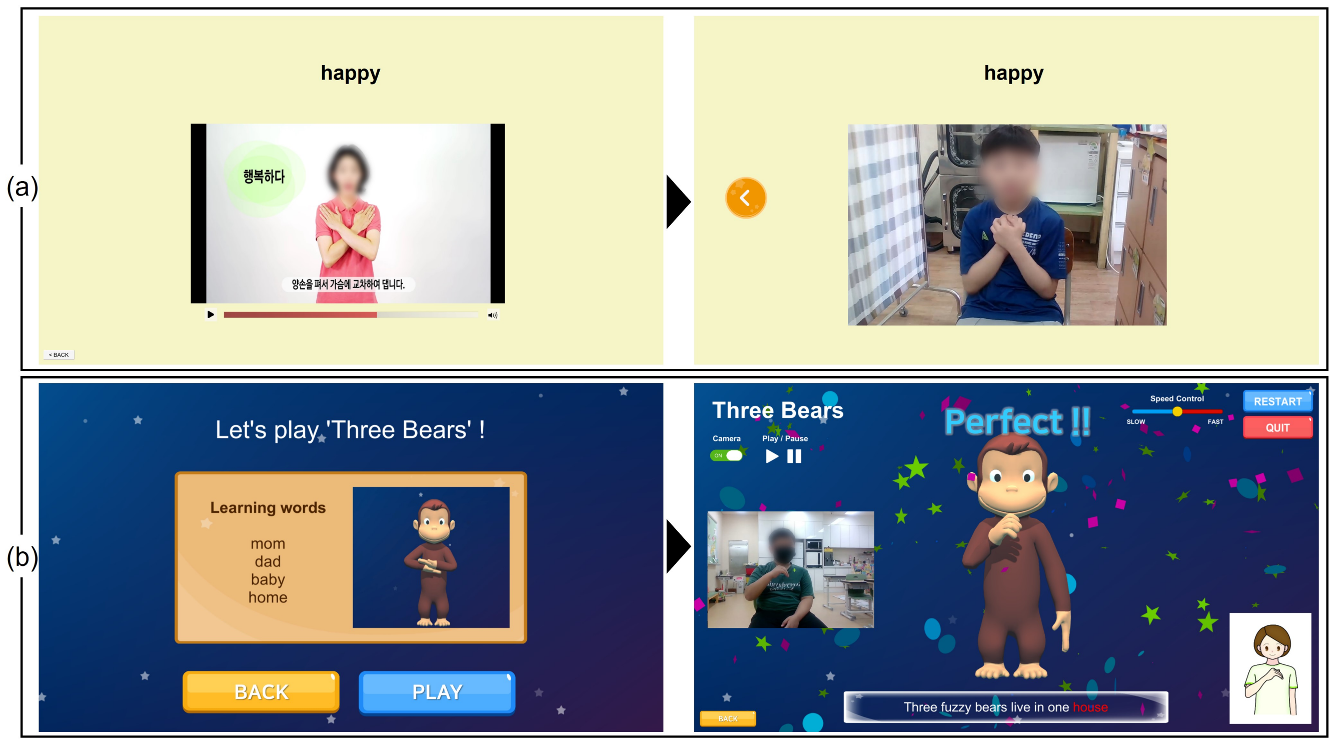


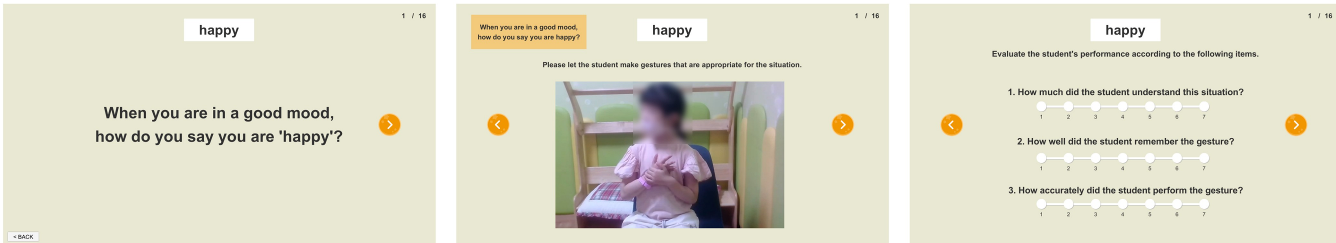
Figure 3: Example of video-based learning (VL) (a) and game-based learning (GL) (b). Teachers demonstrated gestures (words) to their students (left side). Students imitated the gestures from the video or the game (right side).

physical demonstration. Teachers were instructed to repeat each word the same number of times between the two methods.

After completing a learning session, the learner evaluated how fun the day's class was with a one-to-five star rating with the help of his/her teacher, and completed a short recall test for each word. The short-term recall test consisted of three steps (see Figure 4). First, an example sentence of the situation was shown (*e.g.*, "I'm so sleepy. Shall we say we want to sleep?"). Second, the learner recalled and performed the appropriate manual sign gesture. Third, the teacher assessed the learner's performance for three evaluation questions using a 7-point Likert-type scale of agreement ranging from 1 (Not at All) to 7 (Very Much): Q1 (Context-awareness) "How much did the student understand this situation?" (Note that Q1 is intended to identify that the learner understand the concept of a test word rather than to assess the performance), Q2 (Memory) "How well did the student remember the gesture?", and Q3 (Accuracy) "How accurately did the student perform the gesture?" At the end of the week, usually Friday, when having no learning session, a long-term recall test for the entire word set (16 words) was conducted in the same manner as the short-term recall test. Teachers were also given guidelines on recall test scoring in advance to evaluate consistently.

6 ANALYSIS AND RESULTS

Each session took an average of 13.1 minutes, and the Sondam learning time took an average of 5.65 minutes. We collected a total of 128 (4 days × 8 children × 4 weeks) videos and compared the VL and GL approaches by annotating observed behavioral responses due to difficulty of directly asking the children [4, 38]. As shown in Table 3, we categorized the student's behaviors, with respect to four significant difficulty factors identified in the preliminary study: *Attention, Motivation, Emotion, and Gesture Imitation.* Children's emotional variables can be used as factors to evaluate



(a) (b) (c)

Figure 4: Example of the recall test procedure. (a) An example sentence of the situation is given to the student. (b) The student makes a gesture appropriate for the given situation. (c) The teacher observes the student's gesture and evaluates it for three metrics using a 7-point Likert-type scale of agreement ranging from 1 = "Not at All" to 7 = "Very Much."

Table 3: Behavior response variables and signals in video annotation.

Behavior Variables		Signals
Attention	Need for Intervention	Teacher verbal and physical intervention to induce concentration when the child looks 'distracted', 'out of the activity'
	Behavior of Distraction	Inappropriate movements (*e.g.*, teeth grinding, hitting the desk) and loss of movement control (*e.g.*, leaving the seat)
Motivation	Behavior Related to Interest	Engagement with the screen, imitating on screen movements, verbal imitation
Emotion	Positive Emotion	Laughing, smiling, excitedness, clapping, patience
	Negative Emotion	Discouragement, jerking, anger, frustration, fear, agitation
Gesture Imitation	Gesture without Prompts	Watching the screen and copying the gesture without teacher involvement.
	Gesture with Verbal Prompts	Teacher verbal prompting to induce children's gesture (*e.g.*, "let's make a gesture")
	Gesture with Physical Prompts	Teacher physical prompting to induce children's gestures through physical demonstration.

the positive or negative learning experience [4]. For example, the attention-related behavioral variable, *Need for Intervention*, refers to the occurrence of a teacher's verbal or physical intervention to reorient students. Table 4 shows the results of comparing VL and GL by average frequency of the behavior response variables described in Table 3 during the learning process. After the four-week experiment, we conducted individual interviews with the teachers. The one and a half hours interview gave overall feedback on each child's response to the Sondam rhythm games and feedback or suggestions. Interviews were recorded and transcribed with the consent of the teachers. Interview analysis results were used as the basis for qualitative and quantitative research.

6.1 Qualitative Analysis

6.1.1 Improved attention and motivation. As shown in Table 4, children showed higher focus and less distractibility in GL vs VL (see *Need for Intervention* and *Behavior of Distraction*). Interviews by teachers reported short attention and frequent distraction for VL, such as leaving their seats, resulting in teacher intervention. However, teachers reported improved interest and focus for GL, such as positive reactions to the character and songs (C3, C4, C5), and excitement with their reflection in the self-camera (C4). Interestingly, T3 stated, "*children participation in learning fluctuates greatly depending on their daily condition, but they always seem to be interested and attentive in GL.*" The results indicated that the Sondam rhythm game is more effective at maintaining attention and motivation in learning for children with IDD when compared to the VL.

However, this improved outcome in GL was not reflected in all students. C1, a child with high focus in both VL and GL, was absorbed in singing and missed the timing for gesture making with GL. In this case, VL was more suitable, as GL may interfere with a child's focus due to excessive excitement. His teacher (T1) said, *"C1 reacts so positively to the song that he tends to get excited. We need to be a little calmer during learning."* It indicates that GL may need customization for this type of child.

Some children became accustomed to the repetitive songs and began to lose interest by the 4th week. As a result, they became less attentive in GL due to irritability. T2 said, *"C3 had strong cognitive abilities and showed better performance during GL than VL. However, he became accustomed to learning and became bored when he learned the same song repeatedly, so the learning effectiveness decreased."* While GL can motivate attention, it suggests that GL may need more diverse and engaging content.

6.1.2 Frequent voluntary gesture imitation and reduced teacher burden. Children more voluntarily imitated gestures in GL without prompting (see *Gesture without Prompts* in Table 4), and the frequency of voluntary gestures gradually increased over the weeks. In Week 1 and 2, some children had difficulty imitating the gestures

Table 4: The average frequency of behavioral responses observed in each session (standard deviations in parentheses).

Behavior Response Variables	C1		C2		C3		C4		C5		C6		C7		C8		Average	
	VL	GL	VL	GL	VL	GL	VL	GL	VL	GL	VL	GL	VL	GL	VL	GL	VL	GL
Need for Intervention	1.5 (2.8)	1.1 (1.6)	4.6 (3.2)	0.0 (0.0)	12.1 (4.4)	0.0 (0.0)	0.6 (0.6)	0.6 (0.9)	0.5 (0.7)	0.8 (0.6)	9.9 (4.3)	2.4 (1.2)	9.8 (5.4)	3.3 (2.7)	0.3 (0.6)	0.0 (0.0)	4.9 (5.7)	1.0 (1.7)
Behavior of Distraction	1.1 (0.7)	1.5 (1.5)	5.8 (4.7)	1.5 (1.5)	5.0 (2.1)	1.1 (1.5)	1.1 (1.1)	0.9 (0.7)	2.6 (2.3)	6.1 (3.5)	15.0 (7.6)	2.9 (1.6)	2.4 (4.1)	0.8 (1.2)	0.3 (0.6)	0.0 (0.0)	4.2 (5.8)	1.8 (2.5)
Behavior Related to Interest	0.3 (0.4)	0.8 (0.9)	0.0 (0.0)	0.0 (0.0)	0.6 (1.1)	0.9 (0.9)	0.4 (0.4)	2.3 (2.3)	0.4 (0.9)	1.1 (1.2)	0.8 (0.8)	1.1 (1.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.7)	0.8 (1.4)
Positive Emotion	2.4 (2.3)	5.5 (4.3)	0.3 (0.4)	0.8 (0.6)	1.6 (2.0)	1.9 (1.8)	1.8 (1.7)	6.8 (2.8)	1.9 (3.2)	5.3 (5.3)	0.8 (0.8)	0.8 (0.8)	0.9 (0.3)	0.6 (0.4)	1.1 (2.2)	0.1 (0.3)	1.3 (2.0)	2.7 (3.7)
Negative Emotion	12.9 (5.7)	0.1 (0.3)	0.5 (1.0)	1.3 (2.4)	2.6 (4.1)	0.6 (1.3)	0.0 (0.0)	0.3 (0.4)	0.1 (0.3)	0.8 (0.8)	9.4 (7.0)	1.3 (0.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.2 (5.9)	0.5 (1.1)
Gesture without Prompts	6.1 (3.5)	20.8 (9.2)	1.6 (1.1)	15.5 (6.0)	3.9 (4.0)	29.3 (11.8)	6.0 (3.7)	14.5 (8.8)	0.8 (1.3)	0.0 (0.0)	15.3 (7.5)	7.0 (7.6)	3.5 (1.3)	3.0 (6.0)	2.5 (1.8)	22.0 (3.6)	5.0 (5.7)	14.0 (12.1)
Gesture with Verbal Prompts	18.3 (9.0)	3.5 (5.3)	24.0 (6.7)	8.5 (6.4)	33.1 (6.1)	0.5 (1.3)	6.6 (1.8)	9.0 (4.7)	4.5 (2.9)	4.9 (3.2)	18.1 (8.8)	2.6 (2.1)	32.1 (11.4)	40.6 (7.9)	39.8 (14.7)	11.8 (6.4)	22.1 (14.7)	10.2 (13.1)
Gesture with Physical Prompts	1.5 (2.0)	1.3 (2.0)	3.1 (6.7)	1.4 (1.8)	6.5 (3.6)	2.5 (4.6)	2.8 (1.5)	2.9 (2.6)	11.6 (3.1)	13.6 (4.4)	1.5 (1.5)	0.1 (0.3)	9.5 (3.0)	9.0 (3.4)	0.4 (0.9)	0.0 (0.0)	4.6 (4.6)	3.8 (5.4)

of the character as they were unfamiliar with GL. For example, they were unable to distinguish between the character's default gestures and manual gestures. In Week 3 and 4, they adapted to GL and gradually performed gestures by themselves. T3 commented, "*At the beginning of the learning, the child could not distinguish between manual gestures and default gestures. Over time, he began to be familiar with and recognize the timing of the manual gestures.*" And he also stated for C5, "*In game-based learning, her expression became more animated compared to her usual demeanor, and she was very active while imitating gestures. From a long-term perspective, [game-based learning] certainly seemed to work.*"

Teachers pointed out that GL significantly reduced teacher load compared to VL. As shown in Table 4, verbal and physical prompts were frequently needed in VL to redirect the children, but prompting was significantly reduced in GL. Teachers mentioned that one of the main advantages of GL is that children could voluntarily engage in learning with little intervention. T3 stated, "*When teaching children in the field, the biggest challenge is that children do not actively participate. At the very least, it is even difficult to put them into a seat. [In GL,] the children actively attempted to imitate gestures with little teacher intervention.*"

6.1.3 Learning performance: memory and accuracy. Figure 5 shows changes in learning performance score for memory (Q2) and accuracy (Q3) in the weekly long-term recall test. First, we observed an overall increase in memory performance for both VL and GL, with slight fluctuations. This indicated that both methods were effective at memorization of manual gestures. Interestingly, some children's early performance for GL was significantly lower than that for VL (C2, C4, and C7). Findings from interviews suggest that children had initial difficulty in understanding and adjusting to GL, as mentioned in 6.1.2. However, teachers claimed that learning performance increased as children became familiar with GL for Week 3 and 4, as seen in the improved performance of voluntary gestures and reaction rate. This indicates that children do need some time to adapt in GL.

Although children generally became more focused and showed greater interest in GL, this was not true for every individual case. For example, C8 showed high concentration for both methods and made frequent voluntary gestures in GL, but his performance in the recall test was higher in VL. As shown in Table 4, a high frequency of *Gesture with Verbal Prompt* was observed. This child did well with GL, but preferred the interaction with his teacher in VL. When he engaged with the teacher in VL, his performance increased. His teacher (T5) said, "*He enjoyed the game method, but it seems to have affected his performance because he is a student who responds more positively to teacher feedback.*" Establishing a social connection between the character and the child is challenging, but an improvement in this aspect has potential to improve the performance of GL. The learning of C3 and C5 was weaker in GL relative to the other children. We identified two possible reasons from interviews and daily reports. First, if the child is a passive learner, the impact of GL may be weaker. In the case of C5, she was a passive and shy child who rarely performed gestures without teacher intervention. Although she expressed positive emotions for GL, her performance did not improve greatly. Second, children sometimes lost interest over time with GL, as mentioned in 6.1.1. This may explain the decreased performance in GL from Week 3 to Week 4 for C1, C2, and C8. While GL can motivate attention and produce gesture imitation, it suggests that GL may need more diverse and engaging content.

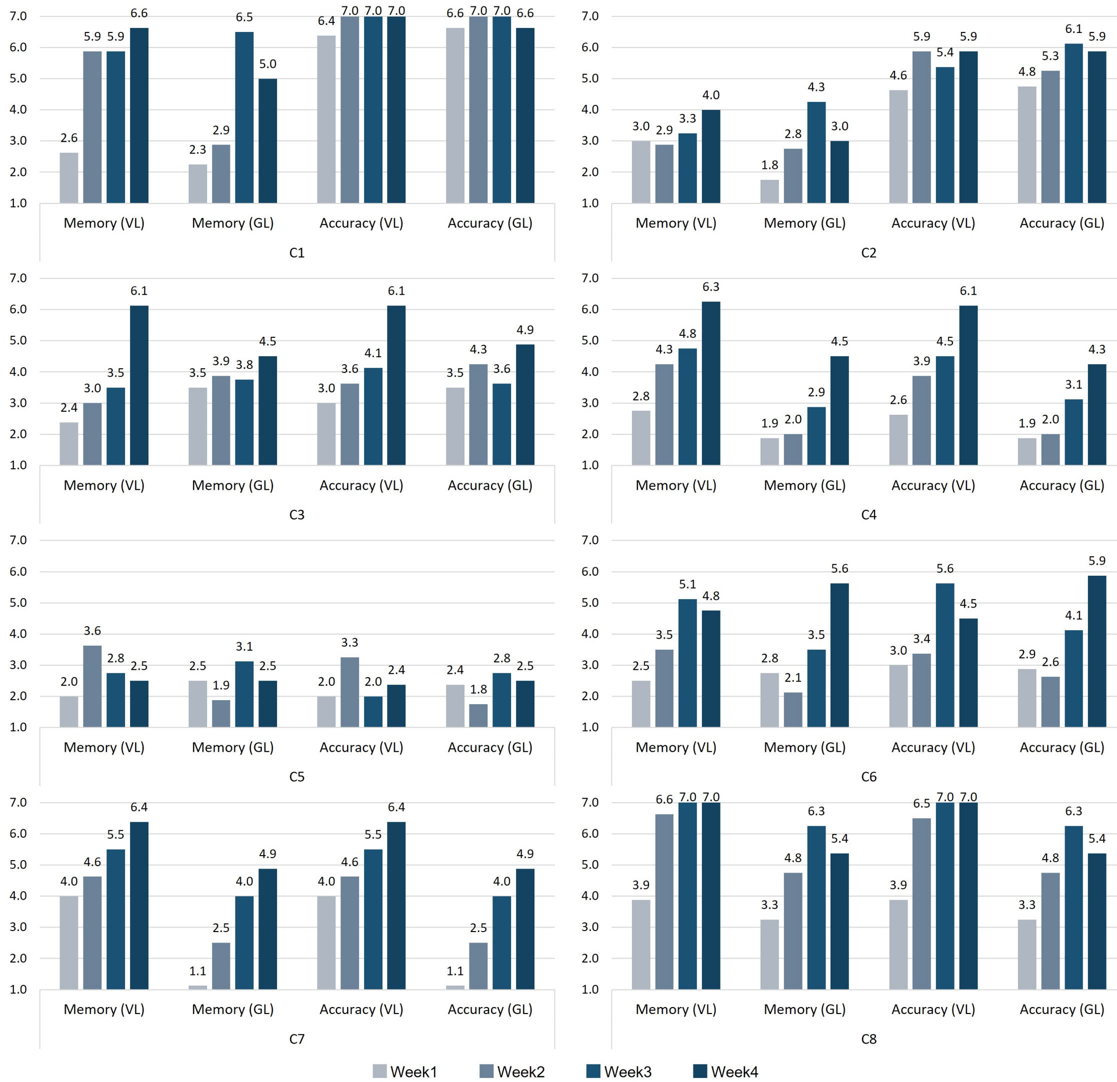


Figure 5: Changes in the memory (Q2) and accuracy (Q3) scores of individual children in long-term recall tests for four weeks.

In terms of accuracy, accuracy scores increased steadily (see Figure 5), but many teachers pointed out that there are limitations for gesture accuracy in GL compared to VL. Except for C1, who showed high accuracy in both methods, most children performed more accurately in VL vs GL. Teachers responded that VL explained concepts and detailed movement about gestures, but GL did not, so it took more time to perform accurate gesture. There was a *preview* scene before the game starts in GL, but the comments showed the need of a better and more detailed intervention.

6.1.4 Habituation for daily life. The ultimate goal of both VL and GL is for children to use manual sign in their daily life. In this study, habituation was not quantitatively measured, but some comments from interviews and daily reports suggests the possibility of improved habituation through GL. Some teachers reported that children talked to them using the manual sign that they had learned through GL. T1 said, "*When I gave an example by saying, 'Teacher, let's do it again,' C1 showed both 'teacher' and 'again' using manual sign.*" T2 said, "*Gestures seems to have been used frequently in real life because it is learned like a dance or song.*" One child showed a desire to play the Sondam game outside of learning sessions. It suggests the potential that GL can be utilized in the home and daily environment. T3 commented, "*C4 even suggested to play the [Sondam] game for other times and used manual sign in daily life. This seems to indicate that GL is effective for habituation for daily life.*"

6.2 Quantitative Analysis

Although the sample size (n=8) is limiting to realistically represent the effect of GL on the general population, we present the results of the quantitative analysis to report the overall tendencies and potential of GL as follows.

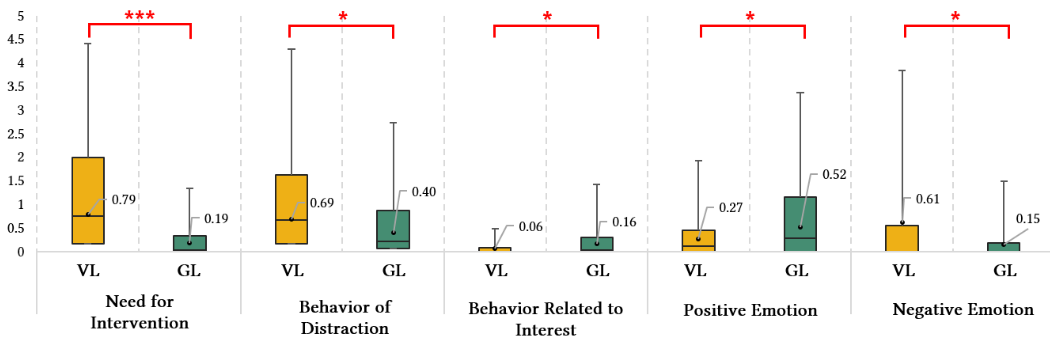


Figure 6: Statistical analysis results of attention, motivation, and emotion ($^*p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$). Y-axis denotes the average frequency of behavioral responses per minute.

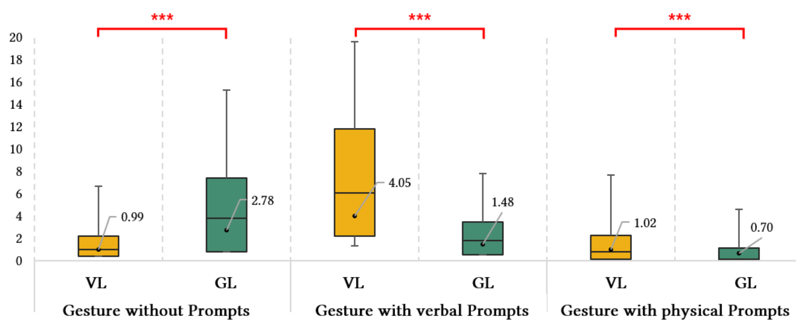


Figure 7: Statistical analysis results of gesture imitation ($^*p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$). Y-axis denotes the frequency of gestures per minute.

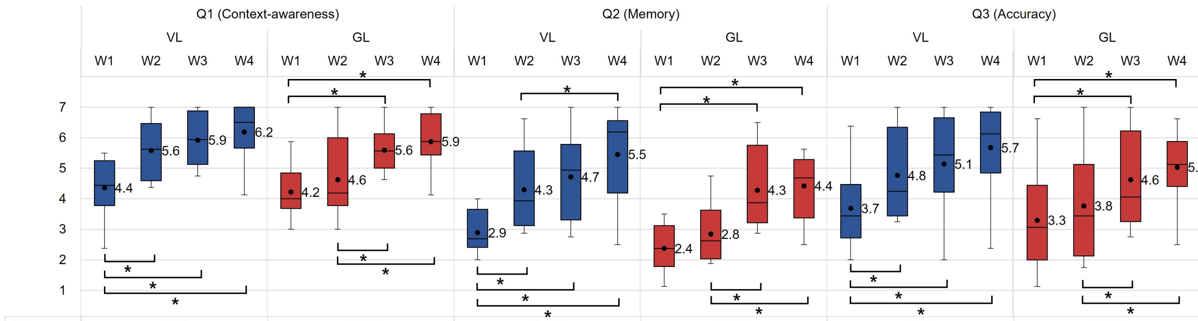
6.2.1 Learning experience. Figure 6 and Figure 7 compare VL and GL according to the number of occurrence of the behavior response variables in minutes during the learning process. A Wilcoxon signed-rank test was conducted to compare children's behaviors for VL and GL during learning. As presented in Figure 6 and Figure 7 most factors of GL obtained more optimal results than VL, by a statistically significant amount. We conducted the following analysis:

Enhancing Attention and Motivation As shown in Figure 6, the *Need for Intervention* (z = 4.41, $p < 0.001$) for VL is higher than for GL, indicating the greater need for teacher intervention to reorient a child's concentration during VL. *Behavior of Distraction* (z = 2.08, p <0.05) events occurred more in VL vs. GL, and the *Behavior Related to Interest* (z = 2.56, $p < 0.05$) events occurred more in GL. This indicates that GL better maintained children's motivation and attention compared to VL.

Enriching Positive Emotion and Gesture Imitation There was a significant difference in the children's *Positive Emotion* (z = 2.72, $p < 0.05$) event occurrences and *Negative Emotion* (z = 2.35, $p < 0.05$) event occurrences for GL compared to VL. GL was particularly effective in inducing emotions despite children with IDD often struggling to express their emotions [59]. Figure 7 showed the results of gestures performed with verbal or physical encouragement. The *Gesture without Prompts* (z = 4.49, $p < 0.001$) count increased significantly for GL vs. VL, but *Gesture with Verbal Prompts* (z = 5.68, $p < 0.001$) and *Gesture with Physical Prompts* (z = 2.67, $p < 0.05$) counts decreased significantly. During GL, children required less encouragement to compete gestures, indicating an improvement to their engagement and positive emotions during the learning process.

6.2.2 Learning performance. Figure 8 shows the distribution and average scores of both short-term and long-term recall tests for all children during the deployment period. Overall, the mean score of both short and long-term recall tests is slightly greater for VL than for GL for all metrics (Q1 Q3). The mean score of context-awareness (Q1) showed no significant difference between VL and GL (p = 0.226), implying the students do not face differing difficulties in comprehending the concept of the words for both methods. For mean scores of the short-term tests, there is no significant difference between VL and GL, except for memory (Q2) ($p < 0.05$). For mean scores of the long-term tests, all metrics showed no significant difference between the methods. In terms of learning performance, VL and GL were not significantly different, but the children empirically received higher scores in both memory and accuracy with VL (note that children may have memorized gestures more accurately by VL because of higher frequency of teacher verbal and physical prompts).

In order to analyze the learning performance over time for each method, we analyzed the distribution of mean score change for all children over four weeks. As shown in Figure 8, the children's



	Q1 VL	Q1 GL	Q2 VL	Q2 GL	Q3 VL	Q3 GL
LT mean	5.51	5.08	4.34	3.48	4.82	4.18
p-value	0.226		0.130		0.318	
ST mean	5.40	5.30	4.80	4.40	5.10	4.90
p-value	0.153		0.020		0.319	

Figure 8: The distribution of long-term recall scores over four weeks (top boxplot) and the mean score and p-value of long-term (LT) and short-term (ST) test (bottom table). The p-value is marked with asterisks ($^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$).

memory and accuracy performance continued to increase for both methods. We observed that the performances for Week 1 & 2 for GL were significantly lower than that for VL. As stated before, teachers empirically noted that it took some time for the student to familiarize themselves with the GL character. Given that children initially needed a period to adapt to the game, our methodology may need a longer timeline of study. Note that due to our limited sample size, the learning performance results for VL vs. GL are theoretical and not realistically applicable as of now. However, our qualitative and theoretical quantitative approaches exhibit the potential of GL, and justify the need for future studies with a larger sample size.

7 DISCUSSION

7.1 Imitation of the Animated Character's Gesture

Children with IDD tend to participate well through computer-based tools, primarily if it includes animated characters [58]. An animated character was used to improve social and emotional understanding for the children, based on theories of Computer-based Intervention (CBI) [12]. Our results showed that children with IDD responded positively to the character's gestures in learning manual signs. The children were curious about the characters, and thus more motivated and attentive. In addition, the prevalence of children's voluntary imitation of the monkey character indicates that an animated monkey-like character is suitable for expressing manual expression gestures. However, when using the animated character to teach manual sign gestures, we received some feedback from teachers. First, children with IDD took time to adjust and imitate character gestures because they had some problems with visual perception (Figure 1E). Many children had difficulty distinguishing between manual sign gestures and meaningless default movements, like shakes performed by the character. The preview function was meant to clarify manual sign gestures, but it was still hard for children to imitate and watch the preview simultaneously (see Figure 1F). Second, the character was limited when performing precise gestures. For example, T1 and T8 reported that, "*there was no problem when it came to learning how to use the entire arm, such as for 'happy,' but hand movements such as 'again' were challenging to follow accurately.*" To prevent such confusion, it may be possible to include a pre-recognition step that explains the character's behavior in detail. We should consider making the character's movements more 'sophisticated' and performing more 'exaggerated movements.'

7.2 Feedback Based on Gesture Recognition

In this study, we provided real-time visual feedback during the game to enhance motivation and engagement. Even simple positive feedback, such as "excellent" and "good," (see Figure 1D) improved active gesture imitation and induced positive emotions. However, teachers proposed that the game should give more detailed feedback, such as "raise your right hand higher," rather than current simple feedback. Additionally, improvements, such as automatic adjustment of game speed according to child gesture accuracy or visual signals, may improve performance in real time [30, 46]. Our in-game feedback was simply "good" or "cheer up." If the feedback is more detailed, children may better correct themselves and improve, *e.g.*, "raise your left hand a little higher and move it quickly." Moreover, it is important for teachers to accurately assess the understanding and learning of a child with IDD and then support the child with individually developed strategies. To improve upon this, we believe that if we are able to generate a quantitative report containing all of these factors, we can greatly assist inexperienced special education teachers.

7.3 Diversity in the Game Design

We received positive feedback from teachers on the diversity of children's songs and learning words. Furthermore, our rhythm game has entertainment, motor, and valuation functions, which can be flexibly applied to various teaching strategies for each child's preference. For example, the Sondam Rhythm Game can be used as a supplement to teacher guided learning or for practicing gestures individually. However, teachers all agreed that the game should support more game content (*e.g.*, character, interaction element, and game level) because the abilities and characteristics of children with IDD vary from person to person. The diversity of game content will improve learning based on each learner's individual tendencies (*e.g.*, time-limited elements, team play mode or competitive mode), and accessibility (*e.g.*, tablet-based).

8 LIMITATIONS AND FUTURE WORK

Our deployment study had a low participant count and varying categories of disability types due to the difficulty of recruiting for AAC research [4, 19, 40] and COVID-19 restrictions. Also, each teacher's detailed teaching style and individual condition were not considered in detail. Precise and detailed gesture improvement feedback should be integrated for future works. Furthermore, the current game version is a learning tool administered by teachers and parents, so it has a complex UI that is difficult for children to use independently. Future research needs to improve the game design so that children can use it independently. We plan to develop this game system with more teacher feedback, and apply it long-term for school and home manual sign learning.

9 CONCLUSION

By identifying a need for an improved manual sign learning system for children with IDD, we designed the 'Sondam Rhythm Game' from domain expert feedback and evaluated its efficacy. We found that a gesture-based rhythm game can support manual sign learning with similar performance to the traditional video-based learning method. The game was especially effective at maintaining attention and eliciting voluntary gestures without teacher's prompts for the children with IDD. Improving the student's learning experience reduced the teacher's intervention load. Through individual analysis and interviews, we further found that manual sign learning strategies have a variety of effects depending on each child's personality. Our game system may be an option to meet the complex need of teaching a manual sign system to children with IDD, and may supplement conventional teaching methods. This paper contributes by providing a more holistic understanding of this under-researched issue regarding manual sign learning in children with IDD, and makes a strong case for the Sondam Rhythm Game's integration and improvement.

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