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Participatory Design of an AI Digital Textbook with Deaf and Hard-of-Hearing Students

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Abstract: Deaf and hard-of-hearing (DHH) children often encounter substantial hurdles in their language development and literacy due to their limited language exposure, which leads to lower print literacy levels compared to their hearing peers. The advent of AI technology offers a promising way to address these challenges when integrated into reading materials. This study examines the design prototype for a Korean AI digital textbook (AIDT) for DHH students, employing participatory design involving both teachers and DHH students. Through encompassing classroom observations, teacher interviews, and prototype drawing activities with students, the study identifies features essential for enhancing the learning experience of DHH students through AIDT. Teacher interviews revealed several critical needs, including the necessity to restructure existing textbooks for DHH learners, incorporate diverse visual materials, address unique linguistic challenges, provide personalized instruction, and support the comprehension of abstract concepts. Furthermore, the prototype drawings by DHH students revealed additional requirements such as the ability to draw pictures from written text, create and share visual materials with teachers and classmates, simplify complex reading materials, provide immediate feedback, and utilize visual aids. These findings underscore the potential of AIDT to individualized learning experiences and alleviate certain teaching burdens, thereby fostering improved learning outcomes for DHH students.

Keywords: Deaf and Hard-of-Hearing (DHH) learners, AI digital textbooks (AIDT), participatory design, print literacy

1. Introduction

Deaf and hard-of-hearing (DHH) children often experience language development delays due to limited language input. Typically, their print literacy competency remains at the fourth-grade elementary school level, even upon high school graduation (Wang et al., 2010), which is largely due to fewer opportunities to engage with spoken language. In Korea, the Ministry of Education has announced plans to introduce Artificial Intelligence (AI) digital textbooks (AIDTs) by 2025. AIDTs are AI-integrated digital learning platforms that provide learning materials and supportive functions tailored to individual students' learning competencies and levels (Ministry of Education & KERIS, 2023). Implementing AIDTs for DHH learners can offer personalized learning experiences adapted to their specific needs and enhance comprehension through various multimedia resources, including explanatory materials in sign language.

The introduction of new technology in the classroom necessitates careful consideration of its relevance and usability from the perspectives of both teachers and students to ensure its effectiveness. However, the development of AIDTs has not adequately addressed the needs of students with special needs, such as DHH learners. One promising approach to making AIDT accessible to a wide range of learners is participatory design (PD), a user-oriented method that involves end-users in the design process through co-creation. Given this

context, this study aims to identify the essential features of AIDTs by collaborating with teachers and DHH students using the participatory design method.

2. Related Research

Deaf and hard-of-hearing (DHH) children often struggle with print literacy, which encompasses reading and writing skills (Alothman, 2021). For most DHH children, written language is their second language (L2), while sign language is their first language (L1) (Evans, 2004; Piñar et al., 2011). Sign language is distinct from written language, with its own grammar and vocabulary. For instance, Korean Sign Language (KSL) comprises manual signs that represent words and non-manual markers, such as head tilts or eye gazes that convey supplementary information like grammatical relations. Additionally, the word order in sign language sentences does not need to be linear, as manual signs and non-manual markers can be used simultaneously (Jo et al., 2022). This distinction underscores the necessity of treating sign language and written language as separate languages and addressing them from a bilingual perspective.

Recent advancements in AI have been widely applied to support DHH learners. To address the communication barriers caused by the use of sign language, real-time sign language interpretation functions are used in various educational settings (Sheng et al., 2024). Recently, the Korean Ministry of Education announced plans to introduce AIDT by 2025. Through AIDTs, students' learning processes can be diagnosed and analyzed by AI, which then provides personalized learning reflecting each student's learning proficiency and pace. Despite these benefits, there is limited research on the use of AI digital textbooks with DHH students. As AI-integrated applications are introduced into classrooms, it is crucial to understand the unique needs of learners with special needs, such as DHH students, to ensure that these technological applications are accessible and beneficial to a diverse range of students.

3. Methodology

3.1 Participants and Research Context

This study was conducted with 13 students and five teachers from grades 3 to 6 (aged 9-12 years) at a special school for DHH students located in Seoul. The study received approval from the IRB ethics committee of the authors' university. Among the participants, eight students used only sign language as their primary means of communication, while five students used both sign language and spoken language. Regarding the severity of their hearing impairment, 12 students were classified as severely impaired, and one as mildly impaired. Additionally, none of the students had prior experience using digital textbooks.

3.2 Data Collection and Analysis

The procedure of this study was structured into three stages based on the participatory design method proposed by Spinuzzi (2005): 1) Initial exploration, 2) Discovery, 3) Prototyping (see Figure 1). During the Initial exploration stage, the research team observed Korean language classes of third and fourth grade students. The observations aimed to understand how DHH students engage with the Korean language lessons, what tools they use, and their learning behaviors. Subsequently, interviews with teachers were conducted to understand their perceptions of the current Korean language lessons with their DHH students, their opinions on the upcoming AIDT implementation, and necessary features of AIDTs for DHH students.

In the Discovery stage, we conducted a 40-minute introduction activity with the students to help them understand the basic concept of AI and interact with AI tools to foster their basic understanding of AI. In the Prototyping stage, the students participated in drawing

a paper-based prototype of AIDTs. Before drawing their prototypes, guiding questions were provided (e.g., What might an AIDT for Korean language class look like? What aspects of Korean language class are difficult for you? How could an AIDT help you?). The drawing activity was carried out in groups of two to three students. Seven students completed the activity individually due to the sign language communication. The students were provided with art supplies and A3 paper to design their own paper-based prototypes. Then, the research team analyzed the prototypes by categorizing the common features and ideas presented by the students.

Stage 1 Initial exploration


Stage 2 Discovery


Stage 3 Prototyping

Figure 1. Participatory design process

4. Results

4.1 Lesson Observations

Two common patterns emerged during the observed lessons. Firstly, there was a prominent reliance on visual materials, with the frequent use of document cameras by teachers. Document cameras, also known as digital overheads, allow real-time image capturing for displaying objects on a screen. Overall, document cameras were favored over computers. For instance, in the third-grade Korean language class, the teacher used a document camera to project vocabulary worksheets onto the screen. Similarly, in the fourth-grade class, students described their weekend activities using photos, displayed from the teacher's smartphone and projected onto the screen using a document camera.

The second observed pattern involved challenges with reading textbooks. In the third-grade lesson, the teacher provided restructured reading materials to aid students' comprehension. Sentences were broken down into smaller parts to assist students in recognizing individual words and explaining their meanings through sign language. While visually representable words were clarified through drawings, abstract vocabulary remained challenging. Additionally, students struggled with understanding the various forms of Korean verbs based on their root forms. Similarly, observations from the fourth-grade lesson indicated that students' sentences tended to be simplistic, with one student often resorting to listing words rather than constructing complete sentences.

4.2 Teacher Interviews

We conducted interviews with five teachers, including one third-grade teacher, two fourth-grade teachers, one fifth-grade teacher, and one sixth-grade teacher. Analysis of interview scripts revealed three major issues with Korean language lessons for DHH students. Firstly, teachers highlighted the inefficiency of current Korean language textbooks for DHH students, emphasizing the need for restructuring text materials to better meet students' unique needs. Textbooks, identical to those used by general students, fail to meet the literacy needs of DHH

students, requiring constant restructuring, which leads to practical difficulties in providing personalized instruction.

Secondly, the teachers emphasized the importance of providing diverse visual materials for learning. Given that DHH students often learn through visual experiences, teachers prioritize using various visual aids to effectively convey educational content. Difficulties in understanding abstract concepts were also mentioned, leading to communicative limitations for DHH students. These limitations often result in problems expressing thoughts and feelings, potentially leading to loneliness as students grow older. This underscores the importance of supporting DHH students in expressing their thoughts and emotions.

Thirdly, the teachers commonly highlighted the need to reconsider how Korean language is taught to DHH students, whose L1 is sign language. These students face challenges in understanding vocabulary and using grammatical structures in Korean language classes. Teachers noted frequent mistakes with particles due to the direct application of sign language expressions in Korean written sentences.

4.3 Students Prototypes

The students participating in the prototype drawing activity comprised four third graders, five fourth graders, two fifth graders, and two sixth graders. Before commencing the activity, the students were introduced to the basic understanding of AI technology. Since there is no direct translation for "AI" in KSL and the concept is abstract, the research team provided various examples to explain its potential applications. Subsequently, the students were asked to express their understanding of AI in short words. Their responses ranged from "AI is magic" to "AI helps people to learn." Based on their basic comprehension of AI, the students engaged in the prototype drawing activity either individually or in groups, resulting in a total of 10 drawings.

From the analysis of students' drawings, five main ideas emerged from the perspectives of DHH students. Firstly, the prototypes frequently featured the function of generating visual representations from written text prompts (see Figure 2). Secondly, the students expressed interest in creating and sharing various visual materials in real-time, inspired by their teacher's use of document cameras in the classroom. For instance, a fourth grader suggested using AI digital textbook tablets to take pictures and instantly share them with the teacher and classmates.

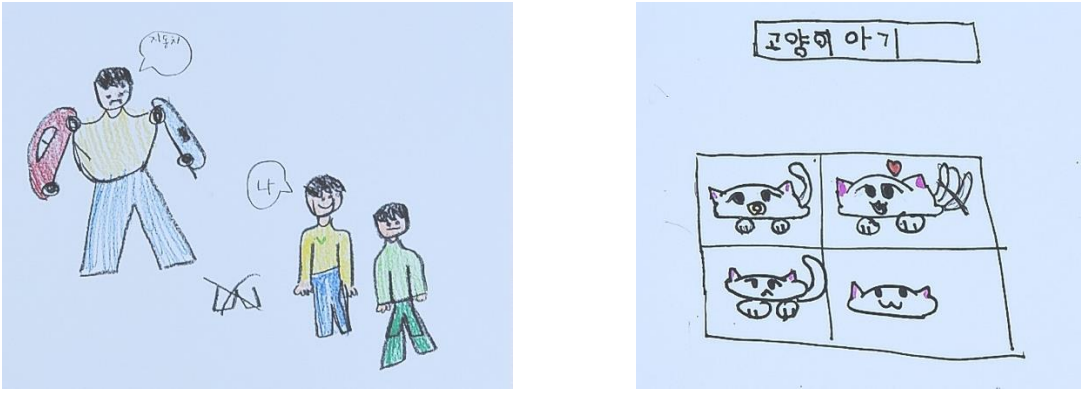

Figure 2. Drawings by third grade students illustrating their imaginative text visualized

Thirdly, the students highlighted the importance of simplifying complex reading materials. Due to their lower literacy levels, they struggle with understanding lengthy and intricate sentences. They suggested a function that simplifies such texts, similar to the techniques of text decomposing and restructuring employed by their teachers (see Figure 3). Fourthly, the students expressed a desire for immediate feedback on their learning tasks. Currently, students often wait for their turn to receive feedback from their teacher during class. To address this, they proposed that AIDTs include tutors capable of providing instant feedback on their answers (see Figure 3). Lastly, the students emphasized the value of incorporating

visual materials such as videos or cartoons into learning activities to aid comprehension. For example, fifth graders recalled their challenges in learning Hangul, the Korean alphabet, during their first-grade Korean language classes. They suggested a feature that provides instructional videos as needed during writing activities (see Figure 4).

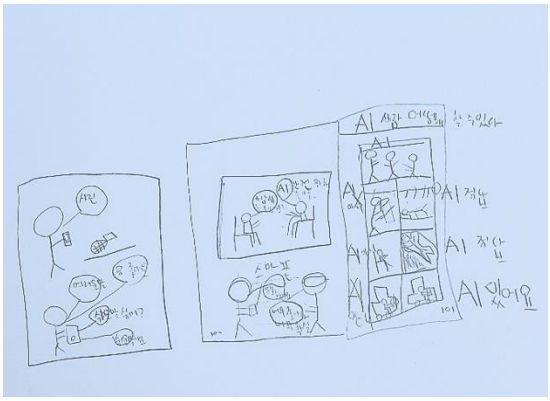

Figure 3. A drawing by a fourth-grade student suggesting the use of AI digital textbook for easy learning

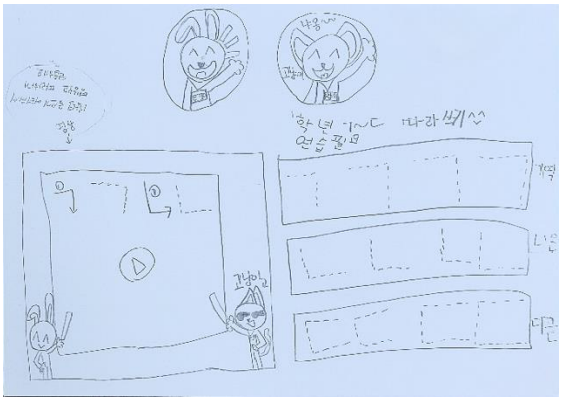

Figure 4. A drawing by a fifth-grade student suggesting the use of videos or cartoons to assist with learning activities

4.4 Common Ideas from Teachers and Students

Several common themes emerged from teacher interviews and students' drawings, highlighting the necessity for visual learning materials, simplification of complex reading materials, and personalized instruction. Based on these insights, the research team developed an initial prototype to explore the potential implementation and effectiveness of the suggested ideas.

Firstly, to provide various visual learning materials, we designed a feature where DHH students can see images corresponding to the words they do not understand. When students click a word, a corresponding image and sign language explanation are displayed (see Figure 5). This function can help DHH students acquire new vocabulary more effectively. Secondly, to make complex reading materials more accessible for DHH students, we divided the paragraphs into sentence units and provided them accordingly. Additionally, the feature includes extra explanations and quizzes for frequently misunderstood parts. Thirdly, to offer personalized instruction, we incorporated an AI tutor into AIDTs (see Figure 6). This AI tutor allows DHH students to interact through text typing or sign language. When students choose the sign language option, they can ask questions in sign language using the camera embedded in AIDTs. Their sign language input is then converted into text, and the AI tutor responds with answers in sign language. This feature can enhance accessibility and provide personalized support for DHH students.

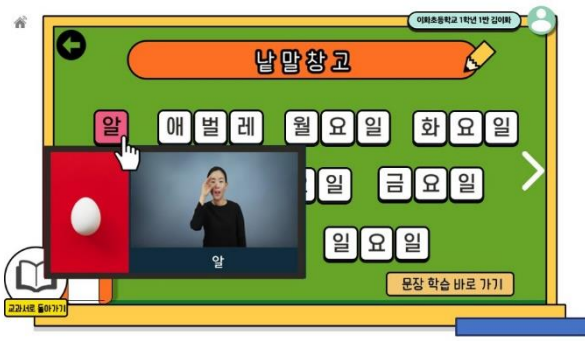

Figure 5. Clicking a word to see images and sign language explanation

Figure 6. An AI tutor to communicate through sign language and text typing

5. Conclusion and Future Work

This study presents the initial steps in designing a Korean AIDT for DHH students. By employing the participatory design method, our main goal was to better understand the specific needs of both DHH students and their teachers, who are the primary users of AIDTs. Through interviews, teachers offered valuable insights into the challenges they face in their classrooms and the essential features of the AIDT based on their teaching experiences. Concurrently, the prototype drawing activity encouraged students to envision their ideal AIDT, generating innovative ideas for integrating AI into learning. Common ideas identified from both teachers and students include the necessity for visual learning materials, simplification of complex reading materials, and personalized instruction. The feedback from teachers and students provides user-centered insights crucial for informing the future design of AIDTs.

Some limitations of this study should be noted. This study was conducted with a small number of DHH students and teachers from a specific school in Seoul, which might be difficult to generalize the results. Therefore, future research should include more students and teachers from various schools and regions. Moreover, some students were not familiar with the concept of AI, which was too abstract to understand, and this resulted in some drawings that were either not appropriate or lacked relevance. Additionally, the AI tutor in the proposed prototype might be limited due to the accuracy of sign language recognition and translation, and is dependent on the availability of a large KSL dataset to improve the recognition accuracy. Moving forward, the next phase of our research is to translate these collected ideas into tangible prototypes. Subsequent usability tests will be conducted to solicit further feedback from teachers and DHH students, aiming to refine and enhance the user experience in subsequent iterations of AIDTs. This iterative process will inform the development of future releases of AIDTs, ultimately enriching the learning journey for DHH students.

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