CAI Theory of Language Recreation Design Practices for Children with Hearing Impairment

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Abstract. In China, approximately 20.54 million people have hearing disabilities, including over 4.6 million children. The language barriers these children face due to their hearing impairments significantly hinder their development. This study proposes the design of a language training system for hearing-impaired children, utilizing Computer-Assisted Instruction (CAI) and the Double Diamond design model. CAI guided this study to fully introduce computer technology into the system to help child users learn independently, while the Double Diamond model provides a structured four-phase design process. This approach aims to create an effective and engaging system tailored to the unique needs of hearing-impaired children, offering a strategic direction for future language training solutions in this field.

Keywords: Children with Hearing Impairment, Computer-Assisted Instruction, Language training, Product Design, Interaction Design

1 Introduction

China has the world's highest population of individuals with hearing disabilities, numbering around 20.54 million, over 30% of its disabled population. Of these, more than 4.6 million are children, who represent approximately 16.5% of the hearing-impaired group. Hearing impairments significantly hinder children's language development, critical for cognitive growth and personal development, especially between ages 3-12. Recent studies highlight the efficacy of Computer-Assisted Instruction (CAI) in enhancing language skills among children with special needs. Research by Tammi D. Waltjer Haverly[1] and others demonstrates CAI's potential in improving language expression and motivation in these children. Furthermore, researchers like Li Jingmei and Liu Zaiquan have successfully integrated Keller's ARCS theory into CAI-based multimedia systems for auditory training[2], enhancing its effectiveness. The Double Diamond model further supports this by guiding designers in creating empathetic, user-centered designs. This study leverages CAI, informed by Double Diamond model insights, to advance language rehabilitation for hearing-impaired children.

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2 CAI Theory and Double Diamond Model

2.1 Overview of CAI Theory

2.1.1 CAI Theory

CAI utilizes computers as educational interventions, facilitating access to course content. Research in this domain primarily concentrates on areas such as special education, medical rehabilitation, and product design. In special education, CAI emulates teacher interactions through computer simulations, enhancing the learning process for students with disabilities and broadening their educational opportunities[3]. For instance, Xiaoyi Hu and colleagues assessed the efficacy of CAI compared to traditional teaching in teaching visual matching skills to students with autism spectrum disorder. Their findings indicated that CAI was more effective in transmitting skills and increasing student engagement, suggesting its potential to alleviate teacher burden and foster learner independence in special education[4].

In medical rehabilitation, CAI has been integrated with immersive clinical simulations to enrich teaching methodologies. For example, Yang Yan and associates employed CAI with scenario simulations in orthopedic nursing, engaging students in comprehensive patient-centered care[5]. In product design, advancements in computer science have facilitated the adoption of CAI principles. Liu Zaiquan and Li Jingmei utilized Keller's ARCS theory within CAI to enhance auditory training systems. Their designs specifically cater to children with hearing impairments, improving both the training experience and outcomes[2].

In summary, years of both domestic and international research have demonstrated that CAI is more effective than traditional teaching methods, especially in auditory training for hearing-impaired children. However, current CAI research for these children predominantly focuses on music, neglecting language correction. For example, as shown in Figure 1， the Hifive communication aid, designed for hearing-impaired children aged 6-13 in their sensory expansion stage, facilitates music sharing and multi-sensory music understanding but overlooks language rehabilitation. Consequently, this study aims to apply CAI theory to develop a language correction training system specifically for hearing-impaired children to enhance their language rehabilitation training effectively.

Fig. 1. ‘Hifive’ music communicator
Image source: Retrieved from https://www.zhihu.com/pin/1749155075417559040

2.1.2 The application of CAI in language training for children with disabilities

Researchers worldwide have investigated the innovative applications of CAI in special education. Fogel and Nancy S. created "Yes or No," an educational game designed to enhance syntactic skills in students with hearing impairments, addressing their specific challenges in English syntax construction[6]. Similarly, Sun Chaoyang and Wu Wei critiqued the limitations of conventional CAI methods, emphasizing improvements through technologies like animation and virtual reality[7]. These advancements aim to bolster language rehabilitation for children with hearing disabilities and broaden CAI's capabilities. Additionally, Mohamed et al. developed a unique educational game tailored for hearing-impaired learners to improve their vocabulary and language skills[8], thus making learning more engaging and enjoyable. Collectively, these studies highlight CAI’s evolving role in special education, adopting a student-centered approach that caters to the distinct needs of disabled children and provides tailored educational tactics to enhance their learning experiences.

3 CAI Theory and Double Diamond Model

3.1 Double Diamond design model

3.1.1 Theoretical overview

The Double Diamond design thinking model, introduced by the British Design Council in 2005, focuses on human-centered design solutions. Applied across education, engineering, and product design, this model fosters user-centric innovation. In education, Ge Fei applied the Discover, Define, Develop, and Deliver phases of the model to reform curriculum[9], enhancing student engagement and creativity through experiential teaching. In engineering, Wang integrated empathy into each phase, developing the L.O.V.E criteria to deepen engineers' commitment to design thinking[10]. In product design, Luo Chenchen and Shi Yuanwu optimized healthcare services for elderly patients using this methodology, creating mobile medical systems and an app to improve community health services[11]. This model's evolving applications highlight its effectiveness in promoting user-focused design and is pivotal in our research on aiding children with hearing impairments.

3.1.2 The process of using the Double Diamond model

The Double Diamond design thinking model consists of four stages: Discover, Define, Develop, and Deliver. In the Discovery phase, designers explore the problem space, gather insights, and generate initial ideas. Gan Zhanwen employs the PEST analysis to identify market gaps in facial therapy[12], validating these through surveys and user interviews to uncover deeper needs. In the Define phase, the problem is clarified and a detailed framework is established. Luo Chenchen and Shi Yuanwu create user personas[11], identifying key emotional triggers and needs during elderly health check-ups, and organize these into themes for optimization. The Develop phase allows for innovative thinking within this framework to address identified needs. Gao Qiyue and colleagues assess pain points and design feasibility, aiming to build user trust[13]. Finally, the Deliver phase focuses on refining and testing solutions. Lin Tingfang and Song Qi iterate on the "Active Aging" model for elder care[14], refining the service system to enhance community eldercare. This structured approach ensures clear organization and continuous refinement in the design process, boosting the effectiveness and impact of the solutions.

4 Analysis of the current situation of children with hearing impairment

4.1 Profile of children with hearing impairment

Currently, China is home to an estimated 85.02 million people with disabilities, including 21.84 million with hearing and speech impairments, and over 4.6 million of these are children with hearing disabilities. Hearing disability is defined as the loss of hearing in both ears or other auditory disorders that impair the ability to hear or clearly perceive sounds. The severity of hearing disability is categorized based on the average level of hearing loss, detailed in the following Table 1:

Table 1. Classification of degree of hearing loss

Degree of disability	Hearing disability level	Degree of hearing loss	Manifestations of hearing impairment without the aid of hearing aids
Severity	Hearing disability level 1	≥91 dB HL	Inability to rely on the sense of hearing for verbal communication, extreme limitations in activities such as comprehension and communication, and very serious obstacles to participation in social life.
↑	Hearing disability level 2	81- 90 dB HL	Severe limitations in activities such as understanding and communication, and serious barriers to participation in social life.
	Hearing disability level 3	61- 80 dB HL	Moderate limitations in activities such as understanding and communication, and moderate barriers to participation in social life.
Mild	Hearing disability level 4	41- 60 dB HL	Mild limitations in activities such as understanding and communication, and mild impairment in participation in social life.

Auditory deficits significantly hinder language development in children, as their language skills often develop in tandem with their hearing abilities. Research indicates that preschoolers with hearing impairments experience delayed language growth, with substantial individual variability. These children typically have lower levels of language comprehension, expression, and development compared to their hearing peers[15]. Despite technological advances like cochlear implants and hearing aids improving hearing capabilities, challenges in language communication remain. Many affected children struggle not with speech production itself, but with subtle language development issues, leading to disinterest in speech during critical early years due to insufficient auditory feedback[16]. Recognizing the critical role of language skills in cognitive growth, Liu Yong advocates for tailored auditory and speech rehabilitation[17]. He suggests regular assessments customized to each child's abilities, with corresponding adjustments to rehabilitation plans to effectively enhance language skills in hearing-impaired children.

4.2 Analysis of design related to children with hearing impairment

Designers and scholars both domestically and internationally have made some achievements in the field of language training for hearing-impaired children. As seen in Figure 2, "Little Ear" is a language rehabilitation training product designed for hearing-impaired children aged 3-6 years old, which combines image and speech recognition technology to help hearing-impaired children with language rehabilitation training.

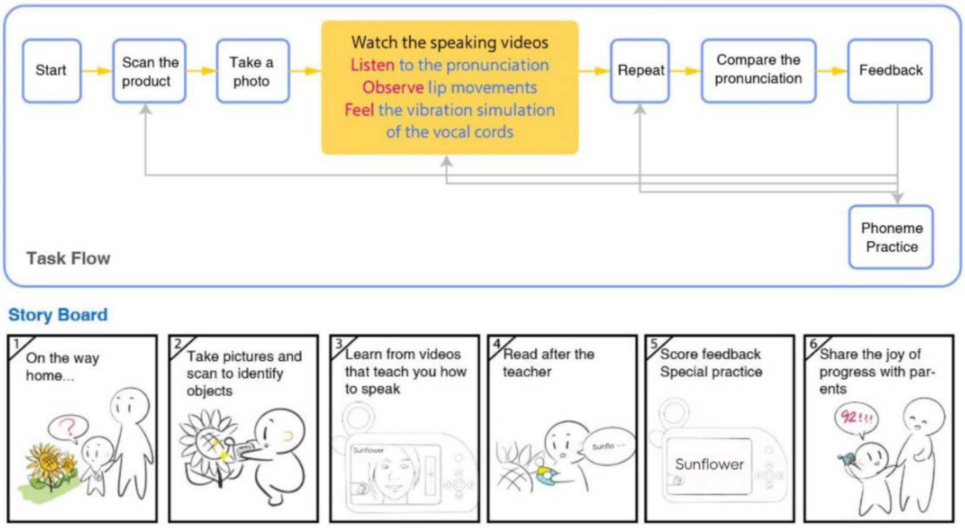

Fig. 2. ‘Little Ear’, Image source: https://art.fzu.edu.cn/info/1069/1001.htm

Kyuseok Lee and Hyunjin Kim's pronunciation correction device for the hearing impaired, COMMU (As shown in Figure 3), consists of two parts that capture the user's pronunciation and guide the user through the pronunciation process, and one part that connects to a mobile phone and displays the waveform and content of the speech, which is combined with AI to analyse whether the speech is clear or not, and to give the user Timely feedback. Users can practice alone, avoiding the embarrassment that may arise when practicing with others, reflecting humanistic care.

Fig. 3. ‘COMMU’, Image source: https://designwanted.com/deaf-technology-products-empowered-design/

The Niubility team has successfully combined existing research and the International Phonetic Alphabet into one application, hoping to use technology to create a better world for special populations. DeafTalk is an auditory-verbal therapy assistant（As shown in Figure 4）. It trains and corrects the pronunciation of hearing-impaired children in a fun way and assists therapists in treating patients with hearing loss, with the ultimate goal of facilitating interpersonal communication between hearing-impaired children and the outside world.

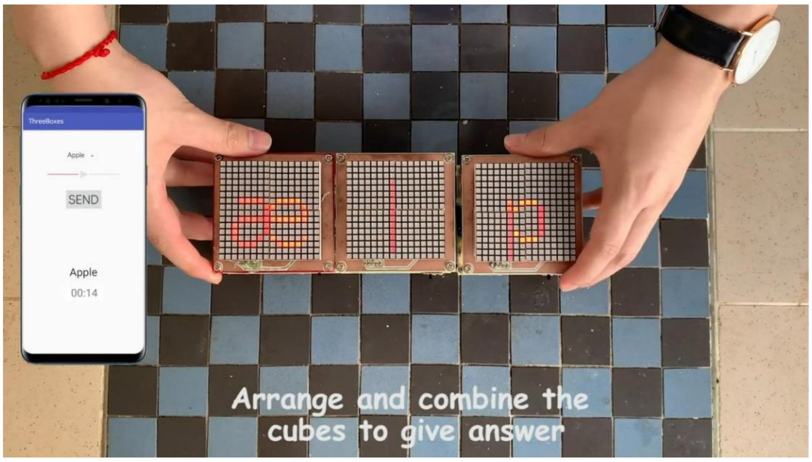

Fig. 4. ‘Deaftalk’, Image source: Retrieved from https://huawei.agorize.com/es/challenges/hackathonsg2022/pages/final-results?lang=en

Overall, designers and scholars have made some important achievements in the field of language training for children with hearing impairment. These products not only use advanced technology, but also focus on fun, making it easier for hearing impaired children to undergo language rehabilitation training.

5 Design development based on the double-diamond model

5.1 Design research to identify problems

The initial phase of the study aimed to collect comprehensive data to thoroughly examine the challenges encountered by special populations, emphasizing the importance of understanding their issues to design truly responsive products.

Data from journal articles, statistical reports, and industry analyses were used, integrating literature reviews with PEST analysis to pinpoint the specific needs of special populations, particularly highlighting that the needs of the hearing-impaired are often underrepresented.

The review identified major challenges for hearing-impaired individuals, including social barriers, limited information access, employment discrimination, educational hurdles, and psychological stress, noting childhood as a critical developmental period. To gain insights into the lives of hearing-impaired children, the study employed experiential methods and empathy mapping. Team members simulated hearing impairments using noise-cancelling earplugs and created empathy maps (referenced in Figure 5), using this role-reversal technique to accurately identify and address the unique challenges these children face, thereby informing effective design strategies.

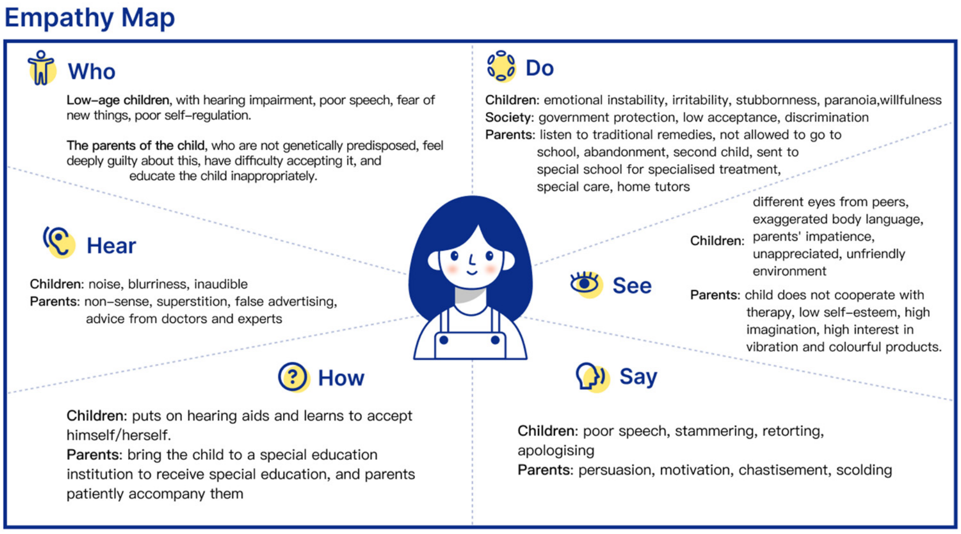

Fig. 5. Empathy Map

5.2 Problem Identification and Design Definition

In the second phase, the study utilized personal interviews and focus group discussions to explore the challenges faced by hearing-impaired children more deeply. The questions covered demographic information such as gender, age, and occupation, along with open-ended inquiries about the children's daily routines and educational experiences. Analysis pinpointed a significant issue: the deficiency of effective language training methods. This insight led to the development of user personas for the primary demographic of hearing-impaired children aged 3-12 years.

The research team interviewed four participants with varied backgrounds, including a special education teacher ('Denial'), parents of hearing-impaired children ('Windsor' and 'Mia'), and a speech therapist ('Lily'), as outlined in Table 2. These interviews, conducted both online and in-person, enriched the study's understanding of the diverse needs related to language training for this group.

Table 2. List of interviewees

Interviewees				Main Content
Name	Gender	Identity	Age	Main Points
Denial	mail	Teacher in special education school	25	Children with weak articulation awareness, lack of attention in class, low cognitive levels, and impaired emotional understanding
Windsor	female	Parent	36	Actual behaviour of the child, details of communication with the child

Mia	female	Parent	29	Cognitive problems of the child, accompanying the child in the training process
Lily	female	Language Training Workshop Teacher	31	Introduction to speech correction methods and teaching needs

Denial, an educator of hearing-impaired children, highlighted challenges such as weak articulation awareness, reduced attention spans, and emotional comprehension difficulties observed during class. He noted that auditory limitations create significant barriers to pronunciation and language expression, often deterring children from speaking and exacerbating communication difficulties. Furthermore, cognitive delays necessitate additional time for these children to comprehend their environment.

In interviews, parents Windsor and Mia shared their emotional experiences, and speech therapy professional Lily discussed language correction techniques. Lily emphasized that therapy goes beyond correcting phonetic and grammatical inaccuracies; it is crucial for boosting self-confidence and expressive abilities. She tailors therapy plans to each child's pace and progress.

The systematic analysis of interview data identified communication and cognitive development as key intervention areas for hearing-impaired children. Consequently, the study proposed a gamified language rehabilitation training tailored for children aged 3-12. The user persona (referenced in Figure 6) is developed to specify the target group, ensuring the research meets academic standards and presents methods and findings clearly and systematically to address these educational challenges.

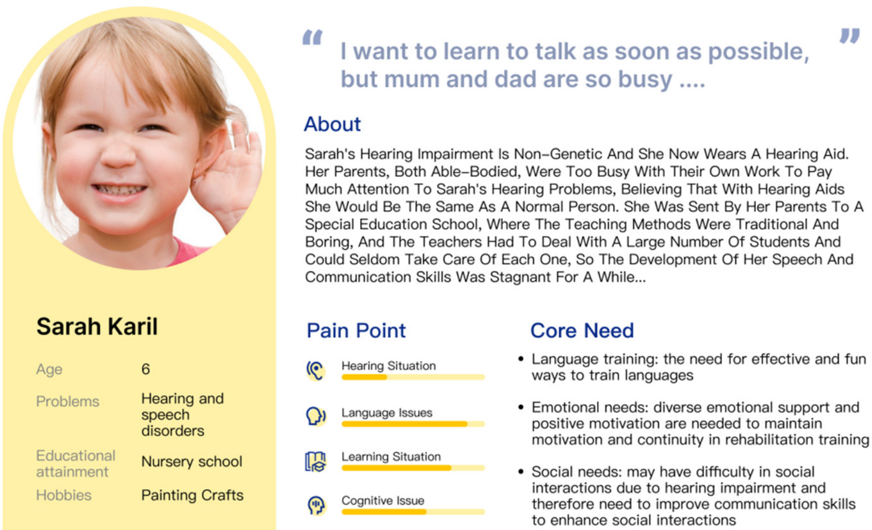

Fig. 6. Persona

5.3 Design Development and Creative Generation

The third phase represents the second stage of divergent thinking in the design process. During this phase, the study explored and synthesized design concepts into actionable plans.

Brainstorming, a method of creative thinking typically conducted in groups, encourages free association and non-linear thought processes by suspending critical judgment, thus fostering innovative thinking. This approach was adopted to expand the design thinking within the study, yielding ideas such as phonetic building blocks and bone conduction voice training chew toys.

After organizing and discussing these ideas, the study established its final design objective: to create a gamified language correction training game tailored for hearing-impaired children aged 3-12. This led to the construction of an information architecture (as depicted in Figure 7), which is the process of designing, organizing, and structuring information to be presented as content within the product. The information architecture of this study is primarily divided into three categories: users, training modules, and training schedule and equipment data. This structured approach ensures that the design aligns with user needs and operational requirements, facilitating effective and engaging language training for hearing-impaired children.

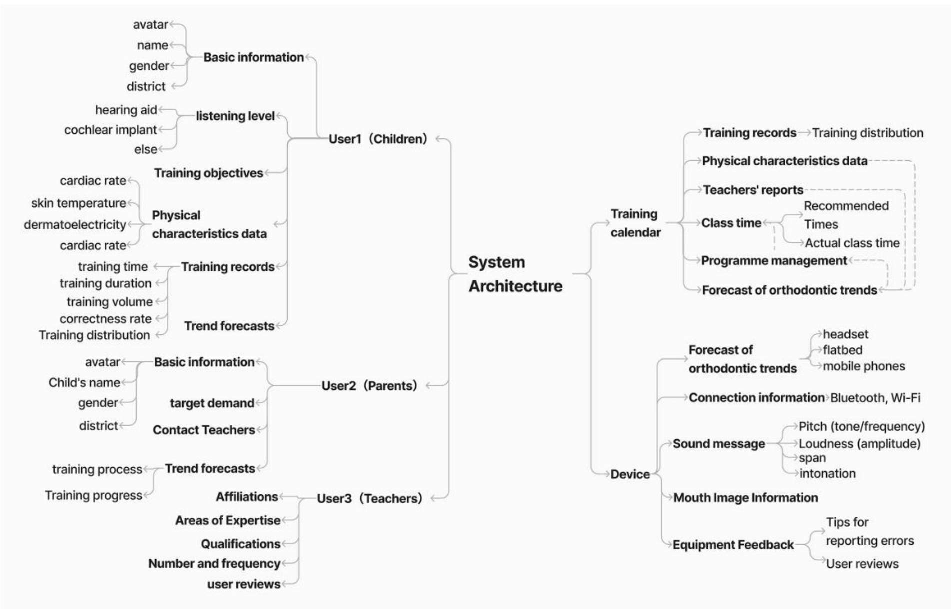

Fig. 7. Information Architecture

5.4 Design Outcomes and Presentation of the Solution

5.4.1 Design Solution

This paper details the challenges in existing language training programs for hearing-impaired children and proposes a new system based on Computer-Assisted Instruction (CAI) and the Double Diamond design model. The system comprises a comprehensive training application supported by hardware, offering interfaces for children, teachers, and parents, creating a holistic training ecosystem. This integrated solution provides a seamless experience across user roles and meets the specific educational needs and accessibility requirements of hearing-impaired children.

The application, "Journey to the Blue Sea," (illustrated in Figure 8) functions on third-party mobile devices like smartphones, tablets, and VR headsets, and uses smart wristbands for data linkage, allowing voice command control of in-game characters. It features three user-specific interfaces: training modules for children, statistical analysis tools for parents, and curriculum configuration for teachers, supporting progress tracking and facilitating school-home collaboration.

The language training is divided into breath control and voice and intonation training, with the interface displayed in Figure 9, addressing the unique rehabilitative needs of hearing-impaired children through structured and interactive modules. These components enhance linguistic capabilities, essential for their communication development.

Fig. 8. Journey to the Blue Sea APP

Fig. 9. Part of the APP interface show

5.4.2 Breath Control Training

In the realm of breath control training, this study introduces the use of virtual objects such as bubbles that children can interact with via mobile devices. By blowing into the device's microphone, children can propel these objects, providing them with a tangible experience of airflow. This technique is designed to enhance children's ability to control their breath during speech correction therapy, thus improving the efficiency of the training process.

5.4.3 Language Training

The app features two characters (as shown in Figure 10) who guide children into the world of the Pink Dolphin, leading the dolphin back to its habitat. By speaking into the microphone of the mobile device and mimicking the software's narration, children's voices control the dolphin to collect oxygen bubbles to swim towards clearer, bluer waters. This activity allows children to assess and enhance their vocal control abilities. Upon completion of levels, rewards are distributed based on the number of bubbles collected, with ratings ranging from three stars (full stars) to no pass, each yielding different amounts of Sea Blue Points—enhancing individual levels. Throughout the progression, the dolphin is gradually led by the children back to its "Blue Planet."

Fig. 10. Character Design

5.4.4 Customized Learning Plans

The system, under the guidance of speech therapy educators, is further tailored according to the individual needs of each hearing-impaired child. Children are able to learn at their own pace, enjoying a stress-free enhancement of their language skills. Additionally, the app includes a progress tracking module, allowing parents and teachers to monitor the child's learning status in real time and provide timely guidance and assistance. Post-training, children can also review their performance to understand the effectiveness of their practice.

5.4.5 Training Calendar

This section could be detailed to explain how the app integrates a scheduling feature that allows for systematic planning of training sessions, aligning daily activities with long-term language development goals. This ensures consistent engagement and measurable progress in the child's language rehabilitation journey.

5.4.6 Application of Artificial Intelligence in Training

The app leverages artificial intelligence for language rehabilitation in hearing-impaired children, incorporating training modules, calendars, and scheduling. It uses open-source models for real-time voice analysis and computer vision to deliver personalized, visual language training. For voice analysis, the app integrates speech recognition, sentiment analysis, and pronunciation accuracy tools to analyze user speech in real-time, providing targeted feedback to enhance language clarity and fluency.Furthermore, the app utilizes computer vision to generate engaging language exercises using images and videos, facilitating realistic practice scenarios that improve comprehension and expression.

5.4.7 Design Evaluation

Design evaluation is crucial in app development, ensuring effectiveness and identifying areas for enhancement through user testing. This study involved five children aged 6 to 11 in a focused evaluation protocol to assess usability, enjoyment, and identify design flaws for future improvements. The evaluation highlighted several usability issues: complex interface components for younger users, unclear navigation and instructions leading to confusion, and inadequate gamification elements affecting engagement.

Recommendations include simplifying the interface with larger icons and clearer instructions, and introducing interactive tutorials to help children adapt to the app's features. Enhancing gamification elements will also improve engagement and educational value. This study aims to refine a language training app for children aged 3-12, advancing their language skills through continuous usability testing and iterative design enhancements..

6 Conclusions

This study applies CAI theory and Double Diamond design to develop a specialized language rehabilitation system for children with hearing impairments. It utilized comprehensive methods like literature review, field studies, and user interviews to understand their specific needs, culminating in a system with diverse training modules and interactive features.

The system includes interfaces for children, parents, and teachers, promoting collaborative training. Modules such as breath control and phonetic training help children enhance their language skills in a gamified environment. The system also provides progress tracking and feedback, enabling real-time monitoring and adjustments by educators and caregivers. Usability tests showed positive feedback, guiding further refinements in interface design and more engaging game elements to improve user experience and outcomes.

In conclusion, this study not only delivers an effective language rehabilitation tool for hearing-impaired children but also enriches the field with practical insights for future research. Ongoing enhancements to this system promise to better support these children, helping them overcome language obstacles and foster personal and social development.

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