

# Augmented Reality for Executive Function Development in Students With Hearing Impairments

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## Abstract

The objective of this research is to develop an Augmented Reality (AR) application to enhance executive brain functions in elementary school students with hearing impairments. The research follows the ASSURE model, incorporating a focus group discussion with students, teachers, administrators, and parents from the School for the Deaf in Chonburi Province, Thailand to refine the application's design, usability, and content appropriateness. Quality assessment was conducted by five experts evaluating key aspects such as activity duration, difficulty level, procedural clarity, and user interface design. A pilot test with five students helped refine the application and develop a user manual. The final testing phase involved 12 students over 8 weeks period, with semi-structured interviews and focus group discussions conducted to assess user engagement, learning outcomes, and curriculum integration. The findings indicate that the AR application includes four interactive learning scenes with three types of activities (problem-solving, matching, and sorting) at adjustable difficulty levels. Pilot testing confirmed usability, while the full implementation demonstrated significant improvements in students' executive functions. These results highlight the potential of AR-based learning tools in enhancing cognitive abilities among students with hearing impairments.

**Keywords:** Augmented Reality Application; Executive Functions; Students With Hearing Impairments; ASSURE Model

## Introduction

Hearing impairment is a significant global issue affecting millions of individuals across various age groups. According to the World Health Organization (2024), approximately 430 million people worldwide, including 34 million children, experience disabling hearing loss. The causes of hearing impairment vary widely, including genetic predispositions, prenatal complications, infections such as meningitis, exposure to ototoxic medications, and environmental factors such as prolonged noise exposure. While medical interventions such as hearing aids, cochlear implants, and speech therapy can help mitigate some challenges, hearing impairments still create significant barriers in education.

Children with hearing impairments often struggle with language acquisition, social interaction, and academic development. Since much of traditional education relies on auditory instruction, these students may face difficulties in accessing curriculum content, participating in discussions, and engaging in collaborative learning (Marschark & Spencer, 2010). Their limited exposure to spoken language can delay literacy skills, comprehension abilities, and overall cognitive development (Hall et al., 2018). As a result, students with hearing impairments often experience social isolation, reduced self-esteem, and an increased risk of academic underachievement or school dropout (Fernández-Gavira et al., 2021). Furthermore, limited access to quality education impacts their career opportunities and economic independence later in life (Sun et al., 2022).

A crucial but often overlooked aspect of hearing-impaired students' educational challenges is the development of executive functions (EFs). Executive functions refer to a set of cognitive skills that enable individuals to plan, organize, regulate their behaviour, and adapt to new situations (Miyake & Friedman, 2012). These functions are essential for academic success, social adaptability, and daily life management (Diamond, 2013). Research suggests that hearing-impaired students are at a higher risk of experiencing deficits in executive functions, particularly in working memory, cognitive flexibility, and attention control (Pisoni et al., 2003). These cognitive difficulties arise from the additional mental effort required to compensate for the lack of auditory input, leading to increased cognitive load and slower information processing. Without appropriate support, these deficits can hinder learning efficiency, problem-solving skills, and overall academic performance (Antia et al., 2011).

To address these challenges, technology-enhanced learning tools such as Augmented Reality (AR) applications have been explored as potential solutions. AR technology overlays digital elements

onto real-world environments, creating interactive and immersive educational experiences. Unlike conventional teaching methods, AR offers visually enriched content that enhances engagement, comprehension, and retention of complex concepts (Ibáñez & Delgado-Kloos, 2018; Radu, 2014). For students with hearing impairments, AR provides an alternative to auditory-dependent learning by integrating visual, spatial, and interactive elements that cater to their cognitive strengths. Studies have shown that AR-based interventions can improve executive functions by promoting active learning, enhancing attention control, and supporting cognitive flexibility through dynamic problem-solving tasks (Merchant et al., 2014; López-Belmonte et al., 2023).

Moreover, AR has the potential to bridge the educational gap for hearing-impaired students by offering customized learning experiences tailored to individual needs. Through real-time visual feedback, gesture-based interactions, and gamified learning environments, AR applications can provide an engaging and accessible platform for students who struggle with conventional instructional approaches. The integration of AR in educational settings has also been linked to increased motivation, higher academic achievement, and improved social interaction among students with disabilities (Radu, 2014).

Despite its promising benefits, the use of AR in enhancing executive functions among hearing-impaired students remains an underexplored area of research. While previous studies have investigated the general effectiveness of AR in education, limited attention has been given to its cognitive impact on students with disabilities, particularly those with hearing impairments (Chen et al., 2015). Additionally, there is a lack of structured instructional models that guide the development and implementation of AR-based learning interventions for this specific population. Addressing these gaps requires a systematic approach to designing and evaluating AR applications that are both pedagogically sound and accessible to students with diverse learning needs.

This study aims to contribute to this growing field by investigating the impact of AR applications on executive function development among elementary school students with hearing impairments. By integrating AR-based learning experiences with established educational principles, this research seeks to enhance cognitive skill development, promote academic engagement, and improve learning outcomes for hearing-impaired students. The findings from this study will provide valuable insights into the potential of AR as an inclusive educational tool and offer recommendations for its effective implementation in special education settings. Ultimately, this research aspires to support the development of innovative teaching strategies that empower students with hearing impairments,

ensuring that they have equal opportunities to succeed academically and socially in an increasingly digital learning environment.

## **Research Objectives**

The objective of this research is to develop an Augmented Reality technology application for enhancing executive brain functions of elementary school students with hearing impairments.

## **Literature Reviews**

### **Augmented Reality Applications in Education**

Augmented Reality (AR) has gained significant attention in the field of education due to its ability to create interactive and immersive learning experiences. Unlike traditional learning methods, AR enhances student engagement by integrating digital elements into the real world, making abstract concepts more tangible (Radu, 2014). Research suggests that AR can improve motivation, comprehension, and retention among students by providing multimodal learning opportunities (Ibáñez & Delgado-Kloos, 2018). For students with disabilities, AR can be a valuable assistive tool, offering visual and interactive elements that compensate for sensory impairments and support individualized learning experiences (Chen et al., 2015).

### **Executive Functions and Their Importance in Learning**

Executive functions (EFs) refer to a set of cognitive skills that regulate behavior, attention, and problem-solving. These functions include inhibition control, cognitive flexibility (shifting), and working memory, all of which are critical for academic success and daily life (Miyake et al., 2000). Deficits in executive functions can lead to difficulties in self-regulation, organization, and decision-making, affecting a child's ability to learn effectively (Diamond, 2013). Studies have shown that interventions designed to strengthen executive functions can significantly improve students' academic performance and adaptive behaviors (Best & Miller, 2010).

### **Challenges Faced by Students with Hearing Impairments**

Students with hearing impairments encounter unique challenges in educational settings. Limited access to auditory information affects their ability to develop language skills, comprehend spoken instructions, and participate in classroom discussions (Marschark & Spencer, 2010). Additionally,

hearing-impaired students often struggle with social integration, which can lead to increased stress, lower self-confidence, and difficulties in collaborative learning environments (Antia et al., 2011). Research indicates that these challenges also impact executive function development, as students with hearing impairments may have delayed cognitive processing and working memory difficulties compared to their hearing peers (Pisoni et al., 2003). Therefore, innovative educational interventions are needed to support their cognitive and social development.

### **The Role of Augmented Reality in Enhancing Executive Functions**

Augmented Reality (AR) is a powerful tool for improving executive functions (EFs), such as working memory, cognitive flexibility, and inhibitory control, which are essential for learning and self-regulation (Diamond, 2013; Miyake & Friedman, 2012). AR's immersive and interactive nature enhances problem-solving and attention control by engaging learners in dynamic, real-world simulations (López-Belmonte et al., 2023).

For students with disabilities, AR provides visual cues and gamified learning, supporting cognitive skill development and engagement (Merchant et al., 2014). Further research is needed to explore AR's long-term cognitive benefits and best implementation practices in education.

### **The ASSURE Model as a Framework for AR-Based Learning Design**

The ASSURE model is an instructional design framework that focuses on creating effective learning experiences through systematic planning, implementation, and evaluation. The model consists of six key phases include

1. Analyze Learners: Understanding students' needs, characteristics, and learning preferences.
2. State Objectives: Defining clear learning goals aligned with educational outcomes.
3. Select Methods, Media, and Materials: Choosing appropriate instructional tools and technologies, such as AR.
4. Utilize Media and Materials: Implementing AR-based activities tailored to students' needs.
5. Require Learner Participation: Encouraging active engagement through interactive learning tasks.
6. Evaluate and Revise: Assessing the effectiveness of the intervention and making necessary improvements.

Using the ASSURE model as a guideline, AR applications can be designed to meet the specific needs of students with hearing impairments while targeting executive function development. Research has shown that structured instructional frameworks like ASSURE enhance the effectiveness of

technology-based learning interventions, ensuring that they are accessible, engaging, and pedagogically sound (Baran, 2010; Model, 2018).

### **Research Gaps and Future Directions**

Despite growing interest in AR-based education, research on its impact on executive function development in students with hearing impairments remains limited. Most studies focus on AR's effectiveness in general learning environments, with fewer investigations exploring its cognitive benefits for students with disabilities (Chen et al., 2015). Additionally, while the ASSURE model has been widely used in instructional design, its application in AR-based learning for hearing-impaired students requires further exploration. Future research should focus on evaluating long-term effects, optimizing AR content for different age groups, and integrating AR with other assistive technologies to create inclusive learning environments.

### **Conceptual Framework**

This research applies principles of Augmented Reality computer application development based on Visuospatial Working Memory theory combined with Visuomotor Adaptation principles. These explain how working memory helps retrieve information for short-term use, processes information, and apply it in Cognitive Processes to build understanding and reasoning in learning. This includes information selection, input, and encoding. Baddeley proposed that working memory consists of 4 key components: Phonological Loop, Visuospatial sketchpad, Episodic Buffer, and Central Executive (Baddeley, 2010).

The researcher is interested in using Augmented Reality technology for training, applying principles from Visuospatial Working Memory theory and Visuomotor Adaptation as the foundation for developing an Augmented Reality computer application. The concept uses augmented reality environmental simulation through perception – vision, touch, and movement – allowing us to interact with the simulated elements. With computer technology assistance, augmented reality hardware works in conjunction with computer application software to help humans receive and understand information more easily. The augmented reality environmental simulation (Augmented Reality) is set up as familiar, relatable situations for children, simulated as Augmented Reality School (ARS).

Brain training with Augmented Reality is based on the integration of 2 theories: Visuospatial Working Memory and Visuomotor Adaptation principles, consisting of (1) Sensory Memory through

perception and interaction with augmented environment via AR system, (2) Encoding, (3) Planning, (4) Movement Control, (5) Active Manipulation, and (6) Adaptation through repetition, improvement, and feedback.

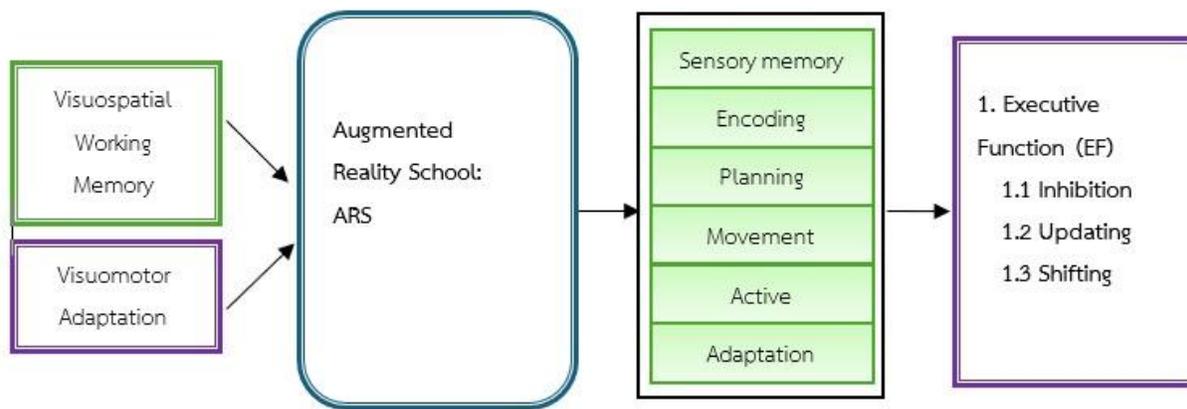


Fig 1 Conceptual Framework

## Research Methodology

### Augmented Reality Application Design

A focus group discussion, following the ASSURE process, was conducted with elementary students with hearing impairments, teachers, administrators, and parents at the School for the Deaf in Chonburi Province. Discussions focused on content appropriateness, user interaction, UI design, and limitations to ensure the application met research objectives and user needs.

### Quality Assessment

Five experts evaluated the Augmented Reality (AR) application for enhancing executive brain functions. Assessment criteria included research objective alignment, activity duration, difficulty level, procedural clarity, and UI design.

### Pilot Testing

A pilot test with five elementary students with hearing impairments was conducted to assess feasibility and refine the application. A user manual was developed following necessary adjustments.

### Application Testing

The application was tested over 8 weeks (8 sessions) lasting 30 – 45 minutes each. Participants could take breaks as needed without affecting training time.

## Usage Data Collection

Data collection involved two methods include

1. Semi-structured interviews with 12 students, assessing content appropriateness, user experience, and engagement.
2. Focus group discussions with 7 stakeholders (administrators, teachers, parents, and students) to evaluate learning outcomes, application usage, and curriculum integration.

## Results

### Augmented Reality Application

To address the research objectives, the researcher utilized focus group discussions with seven relevant stakeholders (administrators, teachers, parents, and students) to design the functionality of the augmented reality (AR) application. The researcher designed the application to include a character selection scene, difficulty levels, one scene for selection, and 4 training activity scenes, with each scene being played twice, for a total of 8 gameplay sessions.



Fig 2 Character, Difficulty, and Scene Selection



**Fig 3** Examples of game scenes, consisting of Space Lab Room scene (top left), Mars scene (bottom left), Forest scene (top right), and Beach scene (bottom right).

Students can select their desired character, name it, and choose an appropriate difficulty level. The researcher will select the scenes to be played in sequence, including: 1) Space Lab Room 2) Mars 3) Forest and 4) Beach, with each scene being played twice. There will be variations in the scene situations and question prompts.

### Evaluation of Application Usage

The researcher had the developed AR application evaluated by five experts in various aspects (Table 1) using a rating scale (1–5 points). A score range of 3.51–4.50 was interpreted as "highly appropriate." The evaluation results aligned with the feedback from interviews with 12 students with hearing impairments, who expressed satisfaction with the AR application.

**Table 1:** Evaluation Results of the AR Application's Functionality

Evaluation topics	Rating Scale (Score)					mean
	Evaluato r 1	Evaluato r 2	Evaluato r 3	Evaluato r 4	Evaluato r 5	
Clarity of images and sounds in augmented reality applications	5	5	5	4	5	4.8

Evaluation topics	Rating Scale (Score)					mean
	Evaluato r 1	Evaluato r 2	Evaluato r 3	Evaluato r 4	Evaluato r 5	
Stability of the system	4	5	4	3	5	4.2
Ease of use	5	5	5	5	5	5
Realism of the experience	5	5	5	5	4	4.8
Appropriateness of the content or learning objectives	5	5	5	4	5	4.8
Level of interest/engagement	5	5	5	5	5	5
Effectiveness in helping to understand the content	4	4	3	3	4	3.6
Safety during use	5	4	5	5	4	4.6
Value of the technology	5	5	5	5	5	5
Overall satisfaction	5	5	4	4	5	4.6

Additionally, insights from the focus group discussion with seven stakeholders (administrators, teachers, parents, and students) highlighted noticeable changes in the 12 students who tested the application. The students exhibited increased attentiveness, improved emotional regulation, and enhanced logical reasoning combined with visual perception—an essential aspect for this group, differing from typical students. The integration of the AR application as an extracurricular activity contributed to the development of executive brain functions, enabling students to build upon their fundamental learning more effectively.

However, both the focus group participants and interviewed students further commented that AR applications remain a relatively new concept in Thai education. Effective usage requires training to foster technological familiarity, and certain application features or functions may need adjustments to better accommodate users who are less accustomed to technology.

## Discussions

The application was designed using the principles of Augmented Reality (AR) combined with the theories of Visuospatial Working Memory and Visuomotor Adaptation. It integrates diverse activities such

as problem-solving, matching, and sorting to develop essential skills while ensuring suitability for students with hearing impairments. The design emphasizes visual perception and interaction, with the following key considerations:

1. Flexibility in Usage: 1.1) The application offers three difficulty levels (easy, medium, hard) to match individual learner needs. 1.2) Four diverse learning scenes are provided, each aligned with different contexts. 1.3) Learners can customize their characters and adjust gameplay according to their preferences.

2. Learning Enhancement: 2.1) Activities span multiple subjects, including mathematics, science, social studies, and Thai language. 2.2) Tasks are linked to real-life scenarios through mission-based learning, promoting analytical thinking and problem-solving skills. 2.3) The variety of activities supports comprehensive cognitive and academic development.

3. Assessment and Evaluation: 3.1) A scoring system is aligned with the difficulty levels, allowing for tailored feedback. 3.2) Progress tracking enables monitoring of individual learner development. 3.3) Assessments evaluate both knowledge and problem-solving abilities, ensuring a holistic approach to learning outcomes.

This application successfully integrates interactive and adaptive elements to create a learning tool that is engaging, effective, and specifically tailored for students with hearing impairments.

#### **Analysis Based on the ASSURE Model** (Makmee & Wongupparaj, 2025).

1. Analyze Learners: Aligns with Hall et al. (2018), who found that elementary students with hearing impairments have unique learning needs that rely heavily on visual learning. Supported by Merchan et al. (2022), which highlighted the distinct cognitive processing abilities of these learners, necessitating appropriate learning tools for effective support.

2. State Standards and Objectives: Reflects Fernández-Gavira et al. (2021), who emphasized designing educational tools that foster social and personal skills. Reinforced by Li (2023), which underscores the importance of learning systems tailored to the specific needs of students.

3. Select Strategies, Technology, Media, and Materials: Consistent with Josman et al. (2008), advocating the use of augmented reality (AR) to teach various skills. Supported by Xu Sun et al. (2022), demonstrating AR's effectiveness as a learning tool for children with hearing impairments.

4. Utilize Technology, Media, and Materials: Corresponds with Zalla et al. (2001), showing that virtual environments enhance planning and task execution. Reinforced by Murray et al. (2019), emphasizing the importance of utilizing suitable technologies in education.

5. Require Learner Participation: Aligns with Hall (2017), highlighting the significance of active learner participation in the educational process. Supported by the World Health Organization (2024), recommend strategies for enhancing education for individuals with hearing impairments.

6. Evaluate and Revise: Supported by Merchan et al. (2022), which highlighted the distinct cognitive processing abilities of these learners, necessitating appropriate learning tools for effective support. Matches Baddeley (2010), advocating the importance of assessing working memory to support learning development. Consistent with Guest et al. (2006), which provided effective methods for evaluating and improving educational outcomes.

This analysis underscores the effectiveness of integrating the ASSURE model with AR technology to address the unique needs of hearing-impaired students, while leveraging research-based strategies to enhance learning outcomes.

### Knowledge from Research

Figure 4 shows the storyboard framework of the augmented reality application in this research. The details are as follows:



**Fig 4** Framework of the Augmented Reality Application

1. Character Selection: Select desired character from available options. (Characters different in hairstyle and clothing)

2. Scene and Difficult Selection: Select desired scene from 4 scenes: Space Lab Room, Mars, Forest and Beach. Each scene being played twice in different activity (choice or sorting). Three difficulty levels available: Easy, Medium and Hard can select.

3. Activity 1 Multiple Choice Problem Solving (choice): When entering a scene, players can click to start answering random questions to unlock items needed in the next activity. These items will appear in random hidden locations in the scene. Questions cover 4 subject areas: Mathematics, Science, Social Studies and Thai Language.

4. Activity 2 Matching Items in the Scene with the Target List: Students are tasked with locating various hidden items scattered across different points within the area to complete the mission objectives in the chosen scenario. Examples of these objectives include:

- Reassembling Computer Components: Find and gather missing parts to repair a spacecraft.
- Searching for Minerals: Locate and collect minerals to replenish energy supplies.
- Retrieving Missing Components: Search for and retrieve vital parts required for mission progress.
- Helping Animals: Use the correct tools to aid animals in need.
- Proper Waste Disposal: Sort waste by type and place it in the appropriate bins for recycling.

This activity is designed to enhance observation, problem-solving, and cognitive skills while engaging students in interactive and goal-oriented tasks.

5. Activity 3 Sorting Problems: In certain scenes, students will encounter randomly generated sorting tasks. They are required to arrange the options provided correctly based on specific instructions.

The questions span across four subject areas:

- Mathematics: Tasks such as ordering numbers, equations, or patterns.
- Science: Sequencing processes, life cycles, or classifications.
- Thai Language: Arranging words, sentences, or ideas based on given criteria.
- English Language: Organizing vocabulary, grammar structures, or sentences logically.

This activity is designed to enhance students' critical thinking, reasoning, and organization skills while providing engaging and interactive learning experience.

6. Show Score: After finished the routine, The score board will show. The higher the difficulty level, the higher the score.

## **Conclusion**

This research study develops an Augmented Reality technology application for enhancing executive brain functions of elementary school students with hearing impairments. Evaluation through in-depth interviews with 12 informants and focus group discussions with 7 stakeholders for design application. The application was positively received by the test group in terms of activity content, outcome tracking, assessment of both knowledge and problem solving skills, scoring system that is consistent with the difficulty to support the sample group with different levels, the operation of UX and UI is easy to understand, the activity duration is appropriate, there are clear illustrations, and it is seen that it can effectively develop executive thinking skills. However, the informants also suggested that the application should be improved to be applied to other variables such as intention, working memory, planning, or language skills, and can be used in other sample groups.

## **Suggestion**

### **1. Suggestions for Applying Research Findings**

When training children with hearing impairments using an augmented reality (AR) application, a sign language expert should be available to provide guidance or assist in familiarizing the participants with the basic gameplay steps. Children with hearing impairments may exhibit varying cognitive development levels even within the same grade.

### **2. Suggestions for Future Research**

Since the sample group in this study consists of elementary school students with hearing impairments, adjustments to the difficulty level of the AR application should be made if applied to students without hearing impairments to ensure suitability for the target group. The AR application developed in this study is designed for single-player use. Future research should consider developing a multiplayer version or incorporating more interactive elements to enhance engagement. This could further support cognitive development in other areas.

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