Development of Augmented Reality Learning Materials for the Hearing Impaired Students in Primary I

Umaporn Ployjiw and Pasapitch Chujai Michel*

***Abstract*—There are challenges in the education of students with hearing impairments, including difficulties in reading and writing the Thai language due to a lack of appropriate learning materials. The COVID-19 pandemic has further exacerbated these issues by necessitating the adoption of technology-based learning methods. In response to these challenges, researchers have proposed the development of learning materials to support the education of students with hearing impairments. These materials will not only benefit the students themselves but also their parents who may struggle to support their children's learning. Furthermore, the use of these materials will contribute to the promotion of inclusivity and equality in education. To investigate the effectiveness of Augmented Reality (AR) books as a learning tool for first-grade students with hearing impairments in primary education, a study was conducted with a target group of ten students (whole level) from Thungmahamek School for the Deaf, selected through stratified random sampling. The results indicated that the development of AR-Books had an effectiveness of 85.33/87, with E_1 and E_2 values exceeding the established standards. In addition, learning outcomes after using AR-Books were significantly higher than before the intervention at a statistical significance level of 0.05. The students' satisfaction with the use of AR-Books was also high.**

***Index Terms*—Augmented reality technology, hearing impairments, sign language**

I. Introduction

Education plays a crucial role in the development of a nation, and learning media serves as a tool for the advancement of education. Presently, there is a diversity of teaching media that utilize technology in their creation. However, these learning media are primarily intended for the general population and not specifically designed for individuals with hearing impairments. In Thailand, it has been observed that the number of people with hearing impairments is particularly high, accounting for 18.78% of the total number of individuals with disabilities [1]. Those with hearing impairments often utilize sign language in their daily lives. However, the learning media available for these individuals is limited and often not suitable for use in a classroom setting. Therefore, this study aims to create a learning media specifically for individuals with hearing impairments, utilizing sign language as the primary medium of instruction in order to support their education [2–4].

Therefore, in order to facilitate communication between these two groups or within the group of individuals with hearing impairments, several researchers [5–7] have utilized modern technology, particularly augmented reality (AR) [8], in conjunction with traditional learning media to enable people with hearing impairments to have greater opportunities for learning [5], allowing them to participate in society more fully on equal footing with the general population [6].

As previously mentioned, researchers are interested in developing augmented reality technology-based learning media for deaf students in grade I primary education using the AR-Book application. This application is a new and innovative learning tool that promotes learning for students at all times. The AR-Book allows students to learn independently through videos or finger spelling and can be used to supplement learning in more difficult content.

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The authors are with Electrical Technology Education Department, Faculty of Industrial Education and Technology, King University of Technology, Bangkok, Thailand. E-mail: umaporn.ployjiw@gmail.com (U.P.)

*Correspondence: pasapitchchujai@gmail.com, pasapitch.chu@kmutt.ac.th (P.C.M.)

II. Theories or Concepts Used in Research

In the study on the development of augmented reality-based learning media for primary school students with hearing impairments, relevant theories and previous research were analyzed to provide a foundation for the study. The goal of this study was to create a learning media tool that can support the learning of students with hearing impairments by using augmented reality technology.

A. Individuals with Hearing Impairments

Individuals with hearing impairments [9] are those who have lost the ability to hear within the range of 25–90 decibels. These individuals can be divided into four levels: mild hearing loss, moderately severe hearing loss, severe hearing loss, and profound hearing loss.

The language of individuals with hearing impairments is called sign language [10, 11]. Sign languages in different countries and regions differ from each other, just like spoken languages. Sign language uses hand gestures, facial expressions, and body language to convey meaning. In addition, sign language in Thailand has various forms, such as gestural language, manual language based on Thai grammar, and Thai sign language [12, 13].

B. Augmented Reality Technology

AR is a technology that combines the real world with the virtual world by superimposing virtual objects on a real environment using three-dimensional images, through the digital camera of a smartphone, which displays the results in real time [7, 8, 14]. The main processes of this technology can be divided into four steps: image analysis, marker analysis, calculation of the three-dimensional position of the marker, and creation of a two-dimensional image from the three-dimensional model.

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C. Tools for Creating Applications

There are various tools that can be used to create applications, and for the AR-Book application, the researchers chose the Unity program [14–16] and the Vuforia program. The reason for choosing these software tools is that Unity is a game engine that supports the creation of both two-dimensional and three-dimensional games and works on various platforms, while Vuforia [14, 17, 18] is a program that helps to develop augmented reality technology and can be used in conjunction with Unity to develop games.

D. Determining the Effectiveness of Media

In this research, we will examine the effectiveness of the media or teaching materials, which is defined as the expectation that students will change their behavior in a satisfactory manner, according to the criteria set by the teacher. The effectiveness will be determined through the "E_1/E_2" ratio [19, 20], which represents the proportion of the effectiveness of the process to the effectiveness of the outcome [21]. A single teacher will conduct the effectiveness test, evaluating the media or teaching materials with the entire class. During the test, the time spent on activities and the behavior of the students will be recorded. In this study, the effectiveness of media will be based on an "E_1/E_2" value. The standard value for evaluating the performance of the AR-Book used in this research is E_1/E_2 of *80/80*, which is the efficiency level of AR-Book that will help learners change their behavior. It is also a level that indicates how effective the AR-Book can be used to teach students.

E. Determining the Effectiveness of Media

Anggracni *et al.* [7] said that hearing-impaired students in Surabaya learn vocabulary through media memorization. including artificial objects and images for remembering the media through images, the media is often used in the form of flashcards. Due to the development speed of Information and Communications Technology (ICT), in this study, an AR-based application integrated with flashcards as a learning tool for hearing-impaired students to learn the vocabulary of Indonesian Sign Language (SIBI), in which the design of the learning materials used the Luther version of the multimedia development method. From the test results, it can be concluded that the AR application system works well, empirically. From the buttons on the AR application, it works 100% according to 97% of the flash card mark detection system functions and will be integrated into the video show. But the applications installed on the device should have at least 1.5 GB of RAM. And have a quad-core 1.4 GHz processor.

Al-Megren and Almutairi [22] say that literacy is the basis for growth. and child development, because it affects the progress of education Therefore, comparing the language to the printed text, reveals differences for hearing-impaired children. When a child with hearing impairment pairs text with sign language (SL), a visual language that has emerged from technological advances, this research aims to improve the educational needs of hearing-impaired children for different sign languages. and fix gaps with the study set. To stimulate user demand for the development of AR applications that support literacy development of Arab children with hearing impairment. Therefore, the tools used in the study consisted of three tools. namely, defining a sample group in literacy that is different and then a questionnaire issued to parents of hearing-impaired children. and teacher interviews along with observing children with hearing impairments the results showed that parents and teachers preferred Arabic SL (ArSL), images and videos. Meanwhile, hearing-impaired children had difficulty with Arabic SL, but preferred finger-spelling.

Cabanillas-Carbonell *et al.* [23] say learning sign language is a big problem. This may be due to the small amount of data access. or because learning sign language is not taught at an early age This article presents mobile application development with augmented reality based on mobile methodology. and consider the influence that affects the Peruvian learning process. The sample group consisted of 30 students, both a control group and an experimental group. Initial efficiency was found to be 23%, and the use of mobile applications significantly improved students' sign language performance by as much as 65%.

R. N. I. A. Razak and N. Senan [24] said that the education of hearing-impaired people is less than that of the general population. May affect communication skills and academic achievement, however, existing applications are developed for the study of sign language, for example as a module to learn. And only the learning materials in the form of videos are used. Using augmented reality (KTBM AR), it has been developed to provide users with learning modules and activities that they can interact with. and able to test their own knowledge. The method used in application development is the ADDIE model, which consists of analysis, design, development, implementation, and evaluation. From the experimental results, it was found that the application was successfully developed at 94% within the acceptable limits according to the System Usability Scale (SUS). Therefore, it can be concluded that KTBM AR is suitable for learning sign language.

From the above article, it can be concluded that learning is fundamental to social development. The hearing-impaired students had a slower learning curve compared to normal students. As a result, learning sign language is problematic. Due to limited information on sign language learning materials can be in the form of artificial objects, pictures, flashcards, and videos. But nowadays, technology has developed rapidly. As a result, the learning materials for the hearing impaired currently use augmented reality technology to develop learning materials. Which is in the form of various applications as an alternative that can be used as a learning medium for sign language.

III. Research Methodology

In this study, the researchers employed a developmental and quality research approach to design and assess the AR-Book media.

A. Population and Sample Group

The study population for the AR-Book research included students from the first grade of primary school at Thungmahamek School for the Deaf in Bangkok, Thailand, totaling 10 individuals. These participants were involved in the research and contributed to its success through surveys

and testing of the AR-Book's development.

The sample group used for surveying satisfaction and testing the development of the AR-Book consists of ten students from the first grade of primary school at Thungmahamek School for the Deaf in Bangkok, Thailand, who can communicate through sign language (with the aid of interpreters) using a purposive sampling method selected by teachers at the school.

The experts in sign language are selected based on their experience teaching sign language for at least three years, totaling five individuals.

B. Research Limitations

Due to the period of data collection during the COVID-19 outbreak, which affects data collection. Therefore, this research has selected only a group of hearing impaired people who are able to communicate in sign language and are equipped with tools for learning with the AR-Book.

C. Research Tools

For the research tools in this study, they are tools used for data collection in order to provide answers to the research problem. In this study, the research tools consist of tools for data collection and tools for data analysis. The researchers have chosen to use a semi-structured interview form [25] to collect data from students and parents. The interview form consists of closed-ended and open-ended questions to elicit useful information and opinions from the interviewees, as well as to suggest directions for AR-Book.

D. Development of Research Tools and Assessment of Tool Quality

For this research, the researcher has created a tool and evaluated its quality. The tool, called AR-Book, is a learning media that assists in teaching Thai language for Grade I students. The process includes data collection, content analysis, and identification of key points, which are as follows:

Data collection was carried out through interviews with teaching staff and analysis of Thai language textbook materials for Grade I students.

Content analysis of the AR-Book involved breaking down the document, speech, or image into its constituent parts to understand its structure and main ideas, as indicated in Table I to Table IV.

TABLE I: ANALYSIS OF CONTENT AND IDENTIFICATION OF KEY POINTS

Chapter	Subject Key Points	Learning Outcomes
Our body	Understanding the vocabulary related to external body parts	When given the spelling or picture of body vocabulary, able to answer questions
My family	Remembering vocabulary related to family	When given the spelling or picture of family vocabulary, able to answer questions
Color	Remembering vocabulary related to color	When given the spelling or picture of color vocabulary, able to answer questions

TABLE II: EXAMPLE SET OF FINGER SPELLING VOCABULARY ON OUR BODY HANDWRITING

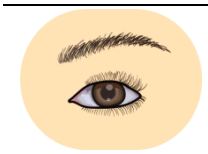
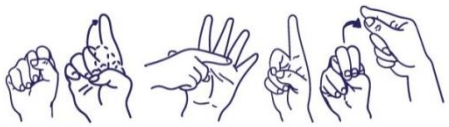
Picture	Finger Spelling	Thai Language	English Language
		ตา	Eye
		หู	Ear

TABLE III: EXAMPLE SET OF FINGER SPELLING VOCABULARY ON MY FAMILY

Picture	Finger Spelling	Thai Language	English Language
		พ่อ	Father
		แม่	Mother

TABLE IV: EXAMPLE SET OF FINGER SPELLING VOCABULARY ON COLORS

Picture	Finger Spelling	Thai Language	English Language
		สีแดง	Red
		สีฟ้า	Blue

Identification of key points involved highlighting the most important information in the content.

Quality evaluation was performed by assessing the effectiveness and usability of the AR-Book through a trial implementation with a small group of students. The results were then analyzed and used to make improvements to the tool.

1) System design: The tool is a visual representation of the system, showing the steps of the system's operation, as shown in Fig. 1.
2) User interface design of the AR-Book application: The AR-Book application consists of five main pages: Home, E-Book, AR, Test, and Others, as shown in Fig. 2.

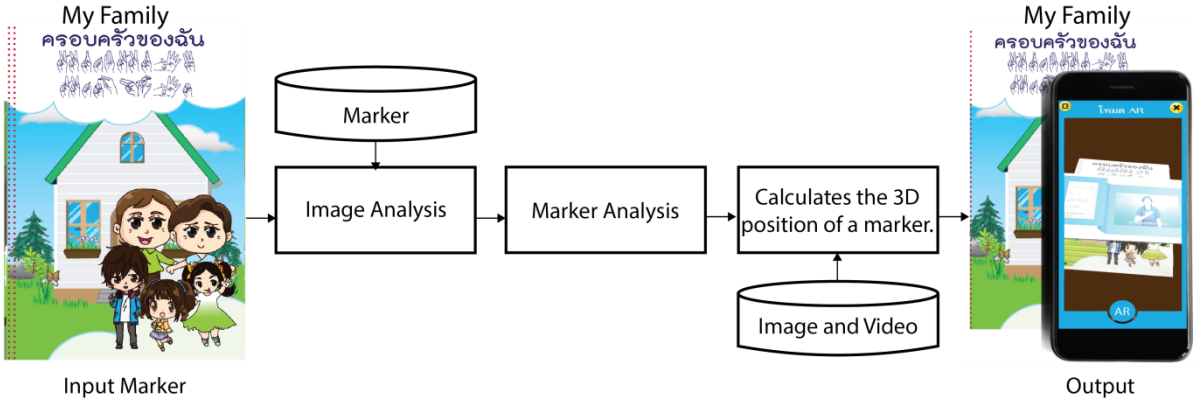


Fig. 1. The concept of AR-Book system.

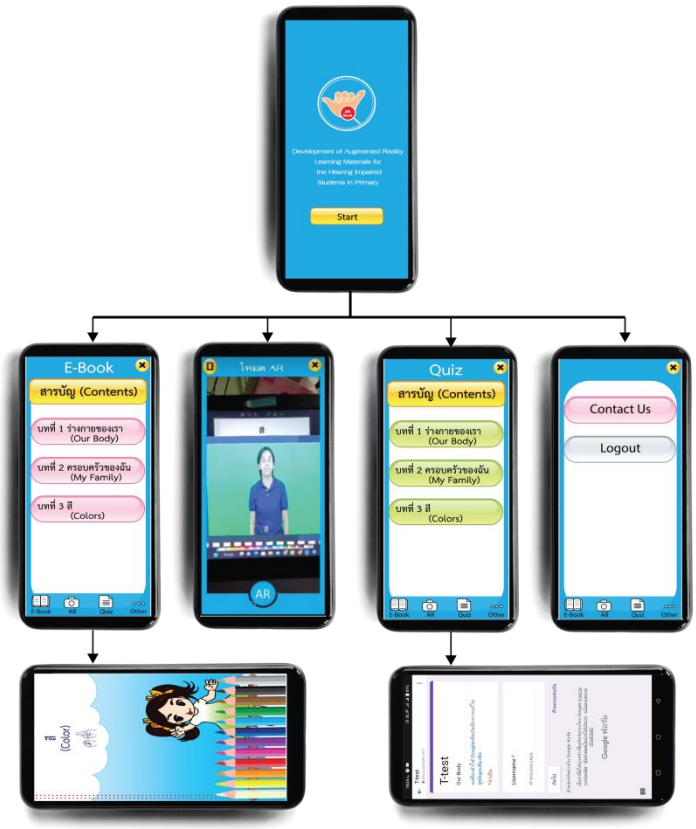


Fig. 2. User interface design in AR-Book.

E. The Process of Creating an AR-Book Application Using the Unity 2018 Program

This process involves the following steps:

1st Step: Creating an AR Marker using Adobe Photoshop. There are certain limitations on the images that can be used as AR Markers, such as being too smooth or not being circular, an example shown in Fig. 3.

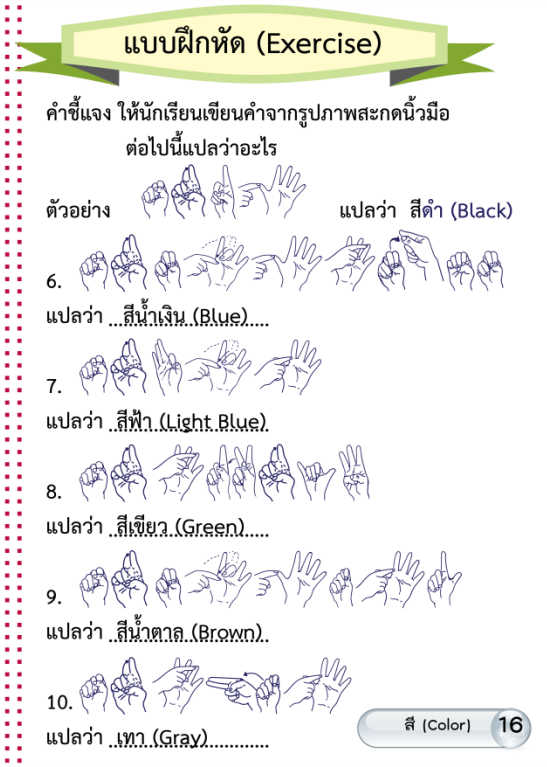


Fig. 3. Design of the AR marker.

2nd Step: The creation of the AR-Book application can be divided into two parts: Part 1 involves creating a database using the Vuforia program, including creating a Target Manager and a License Manager. Part 2 involves the actual creation of the AR-Book application using Unity, including importing the AR Marker and setting up the AR camera.

3rd Step: The software processing in the application consists of the Unity and Vuforia programs.

4th Step: The completed AR-Book is consulted with five expert educators specialized in teaching students with hearing impairments.

5th Step: The AR-Book is revised and improved based on the expert's suggestions, following the example in Fig. 4.

6th Step: The AR-Book, which has been thoroughly revised, was tested with a sample group for a 60-minute teaching session as shown in Fig. 5.

An AR-Book test was developed to measure comprehension when using the AR-Book, which consists of six steps:

1st Step: Study the objectives and scope of the Thai language subject matter.

2nd Step: Analyze and set objectives.

3rd Step: Create a test with three sections.

4th Step: Have the test reviewed by 5 experts to check for content validity (congruence between the objectives and the items) using the Index of Item Objective Congruence (IOC) [21].

5th Step: Calculate the IOC values for the test items reviewed by the experts. If the IOC value of an item is less than 0.5, revise and improve the item based on the feedback of the experts. If the IOC value of an item is greater than 0.6, proceed to trial use.

6th Step: Conduct a trial use of the test with a sample group of 10 students.

Constructing a semi-structured interview to assess the satisfaction of students with AR-Book. Five assessment-based questions were created to evaluate the user satisfaction of AR-Book. Once the evaluation questions were formulated, a consultation with a thesis advisor or language expert in the field of research was sought to receive feedback and make necessary revisions according to the recommendations. Then, consulting with a thesis advisor to determine the sample group. After the sample group is determined, the satisfaction assessment will be tested on students from the Thungmahamek School for the deaf, grade I primary education. The results of the student satisfaction will be summarized using the mean and standard deviation.

From Fig. 1 to Fig. 5, which is shown in Thai language, here we add a description from Thai to English by writing in parentheses, for example Fig. 3, the number six, means blue color.

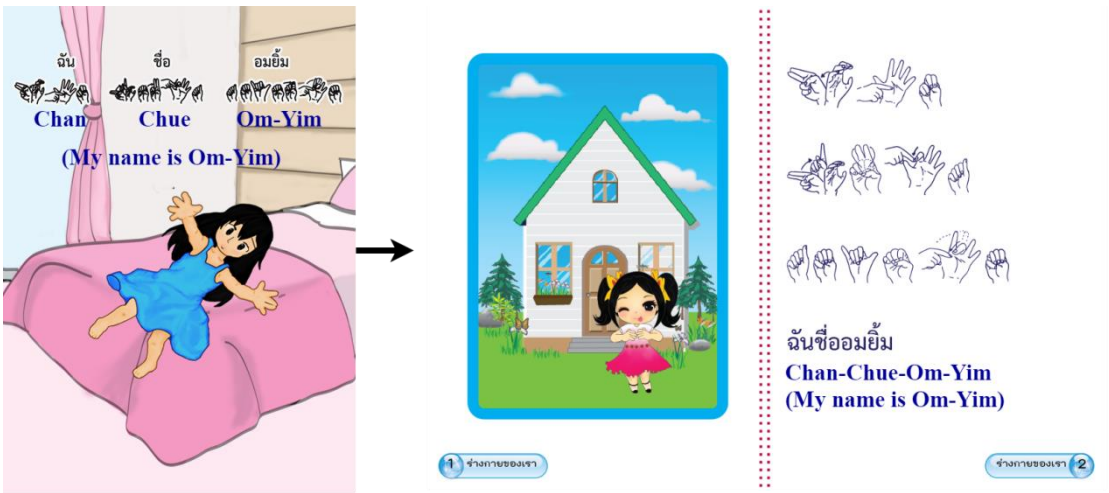


Fig. 4. Modification of the AR-Book in accordance with expert recommendations.

Fig. 5. Testing of the AR-Book with a sample group.

F. Testing Effectiveness and Data Collection

In the testing effectiveness and data collection process, one teacher will test the effectiveness of the media or teaching set with the entire class during the effectiveness testing. The time spent on activities and the behavior of the students will be observed. The estimated values for E_1/E_2 will be approximately 80/80, and the researcher will proceed with the following steps:

1st Step: Collecting data from the pre-lesson test using AR-Book.

2nd Step: Collecting data from the post-lesson test using AR-Book.

G. Data Analysis

The data from the effectiveness test of AR-Book will be analyzed using the E_1/E_2 formula, as shown in Eq. (1) and Eq. (2), to calculate the effectiveness of the computer-aided teaching lesson.

$$E_1 = \frac{\sum X / N}{A} \times 100 \quad (1)$$

$$E_2 = \frac{\sum F / N}{B} \times 100 \quad (2)$$

E_1: the process effectiveness
$\sum X$: the total score of tests
A: the total possible score of all parts of the test
N: the number of students
E_2: the result effectiveness
$\sum F$: the total score of the post-lesson tests
B: the total possible score of the post-lesson test

IV. Study Results

For the study results of the AR-Book application developed by the researcher to determine effectiveness according to the E_1/E_2 criteria of *80/80*, the performance before and after the lesson and the satisfaction of the students with AR-Book was evaluated for students from the Thungmahamek School for the Deaf in Bangkok, Thailand who can communicate using sign language, a total of 10 students. The results are shown in Table V.

TABLE V: Comparison of Methods and Performance Criteria of AR-Book of Students at Thungmahamek School of the Deaf

AR-Book Efficiency	Full Scores	Mean Scores	Criteria	Interpretation
The lesson in the pre-test and the exercise during the study	10	8.53 (85.33)	E_1=80	Above criteria
Post-Test	10	8.70 (87.00)	E_2=80	Above criteria

According to Table V, the average score after the AR-Book test was higher than the average score during the study. In compared to the established E_1/E_2 criteria (80/80), the performance (85.33/87.00) of the AR-Book was higher and higher than the E_1/E_2 criteria.

For evaluating the effectiveness of the AR-Book, the E_1 value was based on the average score of 80% of the number of scores that the students answered correctly from the pre-test and the exercise during the study, and the E_2 value was based on the average score of 80% of the number of scores that the students answered correctly from the post-test. The results showed that the efficiency of the lesson in the pre-test and the exercise during the study (E_1) averaged 85.33%, while the post-test (E_2) averaged 87%.

Consider the total score in the pre-test and the exercise during the study compared with the test score obtained from the post-test. The questions are asked to spell the word in sign language. The out of the ten questions pre-test, there were some questions that all students could answer and some questions that students could answer and did not. The question that students got the most wrong was the one in which 7 out of 10 were misspelled *"mother"*, while the one that was spelled *"hand"* and *"color"* was misspelled by half. The word for which students were able to spell their fingers the most correctly was *"father"*. Considering the post-test, it was found that most of the students had improved in their fingertip reading. Based on post-tests, it was found that most of the students had improved in reading and spelling the given finger spelling pictures. We found that the majority of students answered all ten questions correctly, and the questions that students got the most wrong appeared to be more correct. This can be seen from the word *"mother"* with the number of wrong answers reduced from seven to two,

while the numbers for *"hand"* and *"color"* had fewer wrong answers, dropping from five to three and two respectively.

Analysis of the dependent *t*-test data shows that the mean score before learning was 7.20, while the mean score after learning with the AR-Book was 8.70. When compared, the performance after learning with the AR-Book was significantly higher than before learning at a statistical level of 0.05, as indicated in Table VI.

TABLE VI: COMPARES THE EFFECTS BEFORE AND AFTER STUDYING WITH AR-BOOK

Score	Number	Average	S.D.	t	df	sig
Pre-Test	10	7.20	3.73	3	9	0.01**
Post-Test	10	8.70	3.79			

** Statistically significant at 0.05

Student satisfaction with the AR-Book was assessed using statistical measures consisting of mean, standard deviation, grading criteria, and interpretation of mean. From the assessment of student satisfaction, it was found that students were satisfied at a high level with a statistical mean of 3.90. When focusing on the question, it was found that most students preferred the design of the program following the design of the book. As for the content, the students will like the color more than the content of the family. One of the reasons students disliked family is due to the complexity of the Thai family hierarchy, and another reason that dislikes family content is that the images used are not clear enough to allow students to divide their age ranges. In addition, students expressed personal opinions through a sign language interpreter that they were able to learn vocabulary together with their parents and enjoyed sign language videos that included both finger spelling and subtitles, details mentioned above are shown in Table VII.

TABLE VII: THE SATISFACTION OF STUDENTS WITH AR-BOOK

Question	Average	S.D.	Level of Satisfaction
1. How much do students like AR-Book?	4.20	0.63	high level
2. How do students think about the design of the book?	3.70	0.67	high level
3. How do students think about the design of the program?	3.80	0.42	high level
Total	3.90	0.26	high level

V. CONCLUSIONS

As for the AR-Book that we have developed as a tool for students with hearing impairments, the AR-Book is powerful enough to be used for teaching or self-study. The students when using this media will have a high level of satisfaction. In addition, this AR-Book can serve as an intermediary between parents who are not impaired and those who are hearing impaired, allowing them to communicate at an early level.

VI. RECOMMENDATIONS

From this research, we found some problems that are expected to be useful for researchers who are interested in creating teaching materials for hearing-impaired people. The patterns of sign language should be studied first as people of the same nationality have different patterns of sign language. As well as video media, before creating we need to know the target audience that is being used first. And another important thing is related to the colors used in creating the media that should not use the colors in the group of hot colors, especially red. Because the hearing impaired will spend a long time studying on a mobile device or computer, which can negatively affect their eyesight.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Umaporn Ployjiw designed the model, collected and processed the experimental data, analyzed the data, and wrote the manuscript. Pasapitch Chujai Michel supervised the overall and gives advice about techniques and methods to be used in the process of this research. Both authors discussed the results and contributed to the final manuscript.

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