Analyze the current situation, develop and evaluate the AI-integrated online learning platform solution to support digital transformation of inclusive education programs for hearing-impaired students in Ho Chi Minh City

Summary: Deaf students in Ho Chi Minh City (HCMC) face difficulties in social integration, lack of technology and sign language materials in the Vietnamese general education program, especially in English, History, and Geography. The study used a mixed method, surveyed subjects in HCMC, and identified the need for multimedia learning tools integrating sign language. The results showed that the main barriers were equipment costs and lack of materials. The study developed a multimedia online learning platform integrating Vietnamese sign language, interactive exercises, and real-time AI sign recognition. Testing with students at local deaf schools showed that the system has high potential to improve inclusive learning. The study contributes to promoting equitable learning for deaf students in HCMC and aims to expand nationwide.

Keywords: education hearing-impaired students, digital transformation, Vietnamese general education, artificial intelligence, integrated learning platform.

I. Introduction

1. Research context

Supporting people with hearing loss is an important area of inclusive education and technology to support social communication. According to WHO (2021), 5% of the global population (about 430 million people) have significant hearing loss, expected to increase to 700 million by 2050. Advances in information technology and artificial intelligence(AI) has opened up opportunities to improve communication and learning for the deaf. However, in Vietnam, technological solutions have not fully met practical needs. According toUNICEF, 91% of the 116,000 deaf students in Vietnam, accounting for 9% of the total number of students, are not equipped with multifunctional learning support tools. In addition, only 2% of primary and secondary schools are appropriately designed, only 1/7 schools have specially trained teachers, leading to many educational barriers. The report by the Ministry of Labor, War Invalids and Social Affairs and DRD Vietnam also emphasized that deaf students have difficulty in communication, lack learning resources and assistive technology has not been effectively applied, increasing the gap in access to education. This situation requires technological solutions that are suitable to practical needs to improve the quality of education and the integration of deaf students.

2. Research problem

2.1. Communication

Communication is the biggest barrier for deaf students. (Garrick Duhaney & Duhaney, 2000)According to Nguyen Thanh Binh (2013), sign language is not widely popularized in schools and communities, causing difficulties in social integration. Limited awareness of family and society about sign language increases this obstacle, negatively affecting daily communication and access to knowledge..

2.2. Learning resources

Deaf students around the world face difficulties due to limited access to specialized learning materials. Papers & Magano (2020)emphasized that the current education system does not provide enough specialized teaching materials, especially for subjects that require analytical skills such as History and

Geography.The Adventure (2021)also pointed out that deaf students at universities face significant barriers in accessing learning materials. In Vietnam, the situation is similar to the world,especially in English and History - Geography. Report ofProject to Improve the Quality of Education for Deaf Students at Primary Level through Sign Language(QIPEDC) (2023)showThe general education program has not been adjusted to meet the special needs of deaf students, leading to inequality in access to knowledge.English is a big challenge due to the lack of sign language support materials or visual aids, making it difficult to learn vocabulary, grammar and pronunciation. History and Geography are highly academic, with many abstract terms and complex knowledge. Current teaching methods are mainly based on text and lecture, lacking images, videos or sign language to illustrate. This reduces students' ability to absorb and remember.hearing impaired.

2.3. Assistive technology

Current assistive technology platforms do not adequately meet the needs of hearing-impaired students around the world as well as in the country.(Lartz et al., 2008). Platforms supporting deaf students in Vietnam still lack integration and personalization, making it difficult for students to develop comprehensive skills.area. Platforms with independent features such as VieSignor QIPEDC have not yet digitally converted general education programs such as English, History, Geography with Vietnamese sign language or tools to support social integration. Devices or website platforms, software to support the hearing impaired such as "Speak Your Mind", "SignAll", "SpeakLiz"Although it has certain benefits, it is not suitable for the practical education of students in schools and is not applicable to inclusive education in Ho Chi Minh City as well as Vietnam. Research in Southeast Asia byOsman et al. (2020)also shows that the application of sign language translation is limited in special education.

3. Research objectives

Deaf students face significant barriers in communication, learning resources, and assistive technology, which not only exist independently but also interact, hindering learning and social integration. To address this issue, the study aims to develop an online learning platform that integrates modern technology, supports communication, social integration, and access to specialized learning materials suitable for the Vietnamese curriculum, and integrates Vietnamese sign language data. The study is implemented in three phases: Study 1 helps analyze the needs and difficulties in teaching and learning for deaf students from the perspective of parents and teachers; Study 2 develops a learning platform that integrates sign language and integration support features; Study 3 helps evaluate the effectiveness and practical applicability of the solution.

II. Study 1: Survey analysis of needs, learning difficulties and technology of hearing impaired students in Ho Chi Minh City.

1. Theoretical basis, research gaps and hypotheses

1.1. Theoretical basis

Inclusive education is a field of focus in the context of developing educational technology. According toMarschark et al. (2011)and Mayer & Moreno (2003), multimedia tools such as videos, images and interactive applications effectively support knowledge acquisition, reduce cognitive burden and increase learning engagement, creating a premise for inclusive education.

Theory of needsBradshaw (1972) Emphasizes that correctly identifying learning needs is the basis for designing effective solutions. The UTAUT model(Venkatesh et al., 2003)provides a theoretical framework for evaluating the usefulness, ease of use, and support conditions of technology in education. Multimedia theory ofMayer (2003)emphasizes the role of images and videos in enhancing learning. These theoretical frameworks are the foundation for developing integrated, personalized, and inclusive educational solutions for deaf students.

1.2. Research gap

Despite the progress in inclusive education research, significant gaps remain, particularly in Vietnam. The team focused on the relevant literature and found that there is currently limited research on standardized scales to assess learning needs, communication barriers, and the effectiveness of educational technology solutions for deaf students.Vo Thi Le Huong (2022)mentioned the need for psychological support for deaf students in Dong Nai, but the study has not extended to the technological aspect, especially digital transformation solutions. Although the UTAUT model has been widely applied in the world, research in Vietnam has not deeply analyzed the role of cultural, financial and support factors in implementing educational technology. In general, within the group's capacity, the group has not found any research articles in Vietnam that have deeply studied this topic. Based on these gaps, Study 1 was designed to develop a standard scale to assess the needs, barriers and effectiveness of educational technology for deaf students in Ho Chi Minh City.

1.3. Research hypothesis

Visual images and technologies enhance knowledge acquisition and reduce cognitive load, especially in the education of deaf students.(Mayer & Moreno, 2003). Research hypothesis prediction (H1): The need to use images and technology will be rated highest among the learning need factors.

Communication barriers and inappropriate teaching materials reduce teaching effectiveness.(Bradshaw, 1972). The study predicts that (H2): Difficulties with speaking ability and visual teaching materials will be the biggest barriers in teaching.

Educational technology supports improved learning, especially when designed to meet the needs of hearing-impaired students.(Venkatesh et al., 2003).The research team proposed the hypothesis (H3): The use of technology in teaching will be positively evaluated and have a positive impact on perceptions of learning effectiveness.

According to Nunnally and Bernstein (1994), the scale is reliable when Cronbach's Alpha ≥ 0.7. The scale verification aims to ensure the quality of survey data, creating a basis for in-depth analysis. The research team proposes hypothesis (H4): The scales proposed by the research team will meet reliability and standard value.

These relationships are supported by Bradshaw's (1972) needs theory and the UTAUT model, which emphasizes that both high needs and low barriers contribute to improved learning performance. The research team proposed the hypothesis (H5): Learning needs will be positively correlated with the level of technology use and (H6): Barriers to technology use (KKCN) will have a negative correlation with learning improvement (KQCN).

2. Research methods

2.1. Research design

The study used a mixed method, combining qualitative and quantitative methods to ensure comprehensiveness. The study was conducted in Ho Chi Minh City from June to October 2024, through two phases:

- Quantitative survey:A descriptive cross-sectional study was conducted to measure the prevalence and impact of the study factors.Data were collected through a survey questionnaire including demographic information, difficulties, learning needs and difficulties, technology needs, measured on a 5-point Likert scale. The survey was distributed via Google Form to ensure convenience.

- Qualitative survey: Semi-structured in-depth interviews with 10 teachers and educational staff with experience in teaching deaf students to explore more deeply the problems arising in the teaching process. Data were analyzed by content method.Krippendorff (2018)to identify key themes that aid in interpreting quantitative survey results.

2.2. Research subjects and sampling methods

The study collected data from 70 people at specialized schools for the deaf in Ho Chi Minh City, with 51 valid samples (73%), including 23 parents (45%) and 28 educational personnel (55%), including teachers. A non-probability convenience sampling method was applied, based on referrals from teachers, parents and educational institutions, in accordance with the initial survey to provide baseline data.

2.3. Research process

The research process consisted of six steps: (1) Determining concepts and methods from document analysis and expert interviews; (2) Building a preliminary questionnaire based on qualitative data; (3) Testing the questionnaire, then adjusting it; (4) Finalizing the questionnaire including 43 quantitative questions (5-level Likert scale) and 10 open-ended questions, divided into five groups; (5) Publishing the questionnaire online; and (6) Data were processed using Jamovi with descriptive statistical analysis, Cronbach's Alpha test, and correlation analysis.

2.4. Building a scale

The scale was built through three steps: (1) Identifying key concepts from documents and interviewing experts. (2) Designing a scale with 43 quantitative questions, divided into five main groups: "Teaching methods" (PPDH) with 5 questions, "Learning needs" (NCHT) with 10 questions, "Learning difficulties" (KKHT) with 12 questions, "Using learning technology" (SDCN) with 7 questions and 2 related independent questions (predicting improvement in learning outcomes when using technology, level of technology use); "Technology and equipment difficulties" (KKCN) with 7 questions. In addition, we designed 10 qualitative questions divided into 5 groups and 1 open-ended question to solicit comments for improvement. (3) Test and adjust the scale based on feedback from the survey subjects, ensuring clarity and appropriateness in the assessment.

3. Analysis results

3.1. Descriptive statistical analysis

3.1.1. Descriptive statistical analysis by scale

First, descriptive statistical analysis was conducted to assess the basic characteristics of the data (see Table 1). This analysis provided an overview of the

groups of variables and also determined the suitability of the data for further analyses such as correlation and regression.

Table 1. Descriptive statistics by variable group

Variable	Mean	Median	Mode	Std. Dev	Skewness	Kurtosis	Shapiro-Wilk p
PPDH	19.5	19.0	19.0	3.98	-0.370	-0.003	0.006
KKHT	37.9	36.0	33.0	9.11	0.391	0.346	0.202
NCHT	43.8	45.0	46.0[a]	5.92	-2.56	10.3	<.001
SDCN	24.1	23	22.0	6.24	1.13	1.98	0.004
KKCN	22.5	22.0	22.0	4.14	-0.300	0.678	0.125

Note. N = 51, [a] Multiple modes exist, only the first mode is reported.

The NCHT variable had the highest mean value, reflecting the high demand for the use of visual materials and assistive technology. The KKHT variable had a mean score of 37.9 with a uniform distribution, indicating consistency in perceptions of teaching barriers. The SDCN variable had a mean value of 24.1 and a right-skewed distribution, indicating limited use of technology.KKCNhad a mean score of 22.5 and a normal distribution, reflecting consensus on barriers related to costs and implementation conditions. The PPDH variable had a mean value of 19.5 with a low standard deviation, emphasizing the important role of non-verbal communication such as alphabetic symbols and facial expressions.

3.1.2. Descriptive statistical analysis by observed variables

Teaching methods: The factors in this group were rated positively (M = 3.69–4.08). "Use of alphabetic symbols" and "Use of facial expressions" were rated highly, reflecting the prevalence of nonverbal communication. In contrast, "Use of spoken language" (M = 3.69, SD = 1.049) had a large dispersion, indicating individual differences.

Learning needs: Learning needs were high, especially for "Using images" and "Using technology," emphasizing the role of visual tools in learning. "Learning history and geography with games" (M = 4.20) shows that this need is essential for deaf students but also reflects individual differences in interests and learning abilities. The need for "Learning English as a foreign language" was highly rated (**M = 4.15**), clearly reflecting the learning needs of deaf students in this subject.

Learning difficulties: The main barriers included "Difficulty in speaking ability" (M = 4.08) and "Difficulty in using lecture images" (M = 3.67). In contrast, "Difficulty in communicating with friends" (M = 2.18) was less severe, suggesting that improving communication and visual materials should be prioritized.

Using learning technology: Technology was positively evaluated with "Improved outcomes when using technology" (M = 4.02). However, "Technology usage level" (M = 3.43, SD = 1.237) had a large dispersion, reflecting the heterogeneity between groups.

Difficulty in using technology: The largest barriers were "Cost difficulty" (M = 3.90) and "No hearing rehabilitation" (M = 3.57), reflecting the urgent need for more cost-effective, accessible, and effective technological solutions.

3.2. Testing the reliability of the scale using Cronbach's Alpha

Cronbach's Alpha is used to assess the internal reliability of the variables, reflecting the degree of consistency between items in each scale and the accuracy of measuring the underlying concept. The results of the reliability test are presented inTable 2.

Table 2. Summary results of Cronbach's Alpha of the scales

Scale	Initial item number	Number of items to remove	Cronbach's α (pre)	Cronbach's α (sau)	Mean	SD
PPDH	5	5	0.90	0.90	3.90	0.80
NCHT	10	9	0.86	0.90	4.38	0.59
KKHT	12	12	0.85	0.85	3.16	0.76
SDCN	9	8	0.84	0.85	2.68	0.69
KKCN	7	6	0.71	0.72	3.21	0.59

The scales in the study achieved acceptable to excellent reliability (Cronbach's Alpha = 0.7–0.9) after refinement, ensuring uniformity and the ability to accurately measure latent concepts. The three scalesNCHT, SDCN, KKCNAll eliminated 1 item due to negative or weak Item-rest correlation. Specifically, "Historical and geographical demand for games" (NCHT) were eliminated due to negative Item-rest correlation (-0.03); "Improved outcomes when using technology" (SDCN) and "Aesthetic and usability difficulties" (KKCN) was eliminated due to low Item-rest correlation (< 0.2). The research team eliminated the item "Historical and geographical needs with games" because students had not had the opportunity to access it, leading to inaccurate assessment. "Aesthetic and convenience difficulties" are not the main concerns when using technology. "Improved results when using technology" may not properly measure the "Using learning technology" scale, so it should be considered to be kept as an independent variable. Eliminating items with negative or low Item-rest correlation helps increase homogeneity, reduce noise, and improve the reliability of the scale.

3.3. Correlation analysis between variables

Spearman correlation analysis was applied because most of the variables were non-normally distributed, which helps to determine the relationship between factors accurately without being affected by assumptions about data distribution.

The results of the correlation analysis (see Table 3) showed significant associations between the study variables.KQCN – reflects improved learning outcomes when using technology – is positively correlated withPPDH(r = 0.296) andNCHT(r = 0.448), showing that optimal teaching methods and high learning needs improve learning outcomes when technology is integrated.KQCNalso positively correlated withSDCN(r = 0.231) suggests that frequency of technology use positively supports learning.SDCNpositively correlated withNCHT(r = 0.312), emphasizing that high learning needs often promote technology use. Conversely,KKCNnegatively correlated withSDCN(r = -0.311), reflecting that difficulty in using technology reduces the effectiveness of technology integration. At the same time,, PPDHpositively correlated withNCHT(r = 0.414), affirming that effective teaching methods increase learning

needs. This result emphasizes that educational effectiveness depends on teaching methods, content and flexible application of technology.KQCN, as an independent variable, confirms the importance of technology in improving learning outcomes.

Table 3. Correlation statistics between variables

Variable	PPDH	KKHT	NCHT	SDCN	KKCN	KQCN
PPDH	-					
KKHT	**0.361****	-				
NCHT	**0.414****	0.270	-			
SDCN	0.125	**0.312***	**0.326***	-		
KKCN	-0.179	-0.053	-0.134	**-0.311***	-	
KQCN	**0.296***	0.129	**0.448*****	0.231	0.052	-

Note. * p < .05, ** p < .01, *** p < .001.

3.4. Qualitative data analysis

Content analysis method(Krippendorff, 2018)was used to identify key themes from a survey of respondents with experience teaching and caring for children with hearing loss. Findings revolved around three main aspects: economics and assistive devices, curriculum, and social inclusion.

3.4.1. Economic and unsuitable equipment: Cochlear implants are too expensive and hearing aids do not meet specific needs well, are difficult to maintain, and reduce the effectiveness of learning support.

3.4.2. Curriculum (Personalization, images, communication, course content): The curriculum needs to be adjusted according to the level of hearing loss, integrating images, sign videos and interactive games to improve teaching effectiveness. Gamification of content in History and Geography is highly required, helping to increase interest and receptivity. In English, deaf students have high learning needs but face difficulties due to the lack of sign illustration videos and interactive vocabulary learning applications.

3.4.3. Social (Integration, reducing stigma): Children with hearing loss face difficulties in social integration, including stigma and limitations in vocabulary and communication skills. This highlights the need for technology tools to support vocabulary development and communication skills.

4. Research discussion

From the above results, study 1 concludes with the following research hypotheses:

(H1): The hypothesis is accepted. "Need for visuals" (M = 4.71) and "technology" (M = 4.57) are rated highest, which is consistent with the multimedia theory ofMayer & Moreno (2003). Investment in visual materials and modern technology is essential, especially in general subjects such as English, History and Geography.

(H2): The hypothesis is accepted. "Communication difficulties" (M = 4.08) and "lack of visual materials" (M = 3.67) are major barriers. The solutions proposed by

the research team include training in non-verbal skills and providing visual materials to increase learning effectiveness.

(H3): The hypothesis is accepted. The level of technology use (M = 3.43) is positively correlated with perceived learning effectiveness (r = 0.409, p < 0.01). Consistent with the UTAUT model(Venkatesh et al., 2003), the results emphasize the need to train teachers in technology skills and provide quality equipment, especially in rural areas.

(H4): The hypothesis is accepted. The main scales of the research group achieved Cronbach's Alpha 0.708–0.899, confirming reliability and validity. The scale "Learning Needs" (α = 0.899) highlighted the role of technology and visual elements.

(H5)&(H6): The hypothesis is accepted. Learning needs and technology usage have a strong positive correlation (r = 0.371, p < 0.01), while technology barriers have a negative correlation with learning effectiveness (r = -0.323, p < 0.05). The finding reinforces the theory ofBradshaw (1972), emphasizing the role of visual materials and technology in promoting educational inclusion.

Study 1 helps analyze learning needs, teaching barriers, and the level of application of educational technology for deaf students in Vietnam. Quantitative and qualitative analysis complement each other, clarifying the challenges and needs in digital transformation of deaf students' education. Non-verbal communication such as sign language and facial expressions are highly appreciated, meeting the needs of personalized teaching. The need to use images, technology, and gamification of content in English, History, and Geography subjects is affirmed, showing the potential to improve the appeal and effectiveness of learning through visual and interactive materials. Economic barriers, such as the cost and discomfort of using cochlear implants and hearing aids. At the same time, integration difficulties and social stigma indicate the need for tools to support vocabulary and communication skills.(Garrick Duhaney & Duhaney, 2000). The results confirm the role of digital learning programs integrating visual materials for English, History and Geography, and appropriate technology to improve learning effectiveness and social integration for students with disabilities.hearh.

5. Conclusion

Result Study 1 clarifies the learning needs, educational barriers, and the role of technology in supporting deaf students in Vietnam, especially in English, History, and Geography. The study affirms the importance of multimedia, visual materials, and technology in improving learning effectiveness and social integration. These findings will guide the design of solutions and the development of a multi-purpose online learning platform in Study 2, with appropriate features to meet the urgent learning needs and solve the difficulties of deaf students in the city and expand in Vietnam.

III. Study 2: Designing solutions and developing an online learning platform WHIS integrating AI to support digital transformation of education for hearing-impaired students

1. Problem statement

Deaf students in Vietnam face many barriers in learning and communication due to**lack of visual content and appropriate assistive technology**Devices such as cochlear implants and hearing aids can**high cost**. Presently **There is no system that provides English content according to the General Education Program**

(GDPT) Vietnam have support for hearing-impaired students, while platforms like VioEdu, Monkey Junior, Tienganh123.com only have general materials, and international applications mainly teach ASL (American Sign Language).**Online sign dictionaries such as QIPEDC, Vietnamese Sign Language Dictionary only provide vocabulary videos without test and review functions.** While studying, Roediger & Butler (2011)emphasizes the importance of regular testing to improve memory. Voice recognition applications such as**V-IONE, Live Transcribe has high accuracy but does not support content summarization, limiting its application in learning.** AI research on sign language recognition has mainly focused on**ASL, BSL, while VSL (Vietnamese Sign Language) is not standardized, making it difficult to develop accurate VSL AI systems** (Sahoo, Mishra, & Ravulakollu, 2014).Some domestic applications such as**"The Deaf People" supports text-to-symbol conversion, but with limitations; "Earlie" AI applications recognize voice and gestures but need to improve accuracy and expand features**.

2. Problem-solving approach

Study1 identified the main barriers in educating deaf students in Vietnam, including lack of visual learning materials, limited communication in sign language, and low level of technology application. Based on the analysis results from study 1 and the problem of research gaps, we conducted study 2, with the goal of developing an online learning platform that optimizes the learning process, communication, and personal skills development such as learningEnglish, History and Geography. The approach is designed with inclusive education principles, ensuring that every student, regardless of hearing loss level, has access to optimal content. The platform incorporates multimedia formats while personalizing content to suit the student's ability.

3. System architecture

The system is designed according to a layered architecture (Figure 1), including three main layers: Front-end (user interface), Back-end (application logic processing) and AI Processing Layer (sign language recognition). According to research by Zhenan Tu (2023), layered architecture helps to organize and manage software systems efficiently, improving maintainability, scalability and reuse.

3.1. Front-end: User interface

The system is developed as a web-based platform, using HTML, CSS and JavaScript, ensuring operation on multiple devices. The intuitive interface includes the system home page and 5 beautifully designed sub-feature pages, increasing interactivity and personalization for hearing-impaired students.

3.2. Back-end: Processing application logic

The back-end is developed usingNode.jswith Express.js, manages application logic and handles APIs. The system uses a database MongoDBto store user data, learning progress, and symbol recognition results. The API is designed to deliver learning content, process online tests, and communicate with AI models.

3.3. AI Processing Layer: Sign Language Recognition

MobileNetV2 model is deployed on Flask API for real-time sign language recognition. This is an efficient CNN architecture for real-time user sign language recognition, deployed via Flask API.
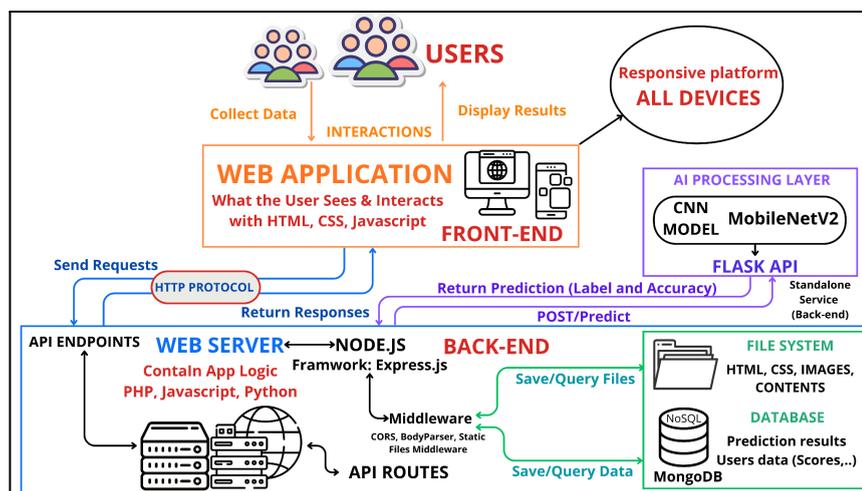
Figure 1. System operating architecture

4. Build the main features of the system

4.1. English learning platform

The system provides an online English learning platform according toGDPTVietnam, specially designed for students with hearing impairments. Lesson content integrates sign language, illustrations, subtitled videos and multimedia materials to enhance comprehension. To support students with different levels of hearing loss, the system allows for personalized learning content, including audio lessons, audioless lessons using only signs and images, as well as materials to support language skills development. In addition, the English test uses gamification to increase learning motivation and effectively help students improve their vocabulary and grammar skills.

Figure 2. Main home page to access WHIS system features

4.2. Foundation of History - Geography

The system provides an integrated approach to sign language for two important subjects: Vietnamese History and Geography, helping deaf students easily acquire knowledge through visual aids. The lectures are designed based on an interactive learning model. This feature allows students to experience historical sites and scenic spots in the three regions of North - Central - South through a 3D photo library, interactive videos and 360-degree experiences. Applying this technology helps increase interest and the ability to connect knowledge with practice, while raising cultural and historical awareness.

4.3. Integration support feature library

The system integrates an extensive feature library to support the communication and learning process of deaf students. Key features include: (1) Integrated sign

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language dictionary to enhance memorization and testing (2) Speech-to-text conversion tool with summary of main ideas (3) Chatbot to support vocabulary improvement, sentence writing support (4) The system integrates a hearing test tool according to WHO standards, helping to assess the hearing level of students to personalize learning content. These features help deaf students easily integrate into the learning environment and communicate more effectively with those around them.

4.4. Assistant support for sign language performance practice

The integrated AI assistant system helps students practice performing Vietnamese sign language through the camera, providing real-time feedback by comparing gestures with standard videos from experts. Deaf students not only master the correct sign language but also improve their real-life communication skills.

5. System development process

The system is built based on the Spiral development model combined with Agile elements. The Spiral model ensures continuous iteration of development stages, allowing adjustments according to user feedback and early detection of problems during the construction process. Meanwhile, the Agile element focuses on flexibility, optimizing experience and efficiency by implementing small features in stages for easy testing and improvement (Boehm, 1988; Beck et al., 2001). Study 2 was conducted in 3 steps: (1) Requirements analysis; (2) System design; and (3) Development and testing: Modules in the system are developed in short sprints (phases), each sprint lasting about 1 to 2 weeks, ensuring continuous integration and testing. The research team implemented testing forms according to the iteration and risk orientation of the spiral model (Boehm, 1988).

6. AI models and algorithms

6.1. Model development process

6.1.1. Data collection and preprocessing

The research team collected and processed a dataset of Vietnamese alphabet and numbers (0-9) in Vietnamese sign language, with 1,500 images for each class, a total of 39,000 samples. The data was collected from deaf students at Hy Vong School (District 6, Ho Chi Minh City), 15 teachers at deaf schools, 2 experts from QIPEDC, and 10 volunteers. To optimize the collection process, the research team developed a Python application that supports recording video data frame by frame and automatically sending the data to the server. The data was divided in the ratio of 80%-10%-10% for training, validation, and testing. Before training,MediaPipeis used to detect and draw feature points on the image. The image is resized (224x224) and data enhanced, sharpened applying Gaussian Blur and Histogram Equalization.

6.1.2. Model training

MobileNetV2 model is selected as the optimal model.(Table 4)and fine-tune on the collected dataset, using pre-trained weights from ImageNet to speed up learning and optimize performance. The model is trained with the Adam optimizer (learning rate = 0.0001), 50 epochs, batch size = 32, and the Categorical Cross-Entropy loss function, suitable for multi-class classification problems. The training results show that the model achieves 98.57% accuracy on the test set and 98.23% on the validation set, with decreasing loss and stable convergence.

6.2. AI model testing results

Table 4. Performance comparison of tested CNN models

Model	Accuracy (%)	Average F1-Score	Inference time (ms)	Model size (MB)
VGG16	94.5	0.931	220	138
ResNet50	96.2	0.945	180	98
EfficientNetB0	97.1	0.964	150	65
InceptionV3	96.8	0.949	160	92
DenseNet121	97.3	0.967	145	88
MobileNetV2	**98.57**	**0.985**	**95**	**12**

The research team tested and fine-tuned popular CNN models for Vietnamese sign language recognition, including VGG16, ResNet50,EfficientNetB0, InceptionV3, DenseNet121and MobileNetV2.MobileNetV2achieves optimal performance with 98.57% accuracy, F1-Score 0.985, 95ms inference time and 12MB size, suitable for resource-limited devices.DenseNet121 and EfficientNetB0have high accuracy (97.3% and 97.1%) but longer inference time. Other models are large in size or slow in speed, makingMobileNetV2become the optimal choice.

7. Conclusion

Research 2 has developed an online digital learning platform that integrates AI to support deaf students. The platform is designed to support deaf students to learn well in English, History, Geography and communication, and practice Vietnamese sign language. Compared with existing platforms, the system not only supports learning but also enhances social integration, reduces costs and digitally transforms inclusive education in Ho Chi Minh City. To assess the practical impact and level of optimization, Research 3 will continue to conduct large-scale testing with groups of students, teachers, and parents to ensure the feasibility, effectiveness, and scalability of inclusive education in Vietnam.

IV. Study 3: Practical experiment and evaluation of the effectiveness and potential of an online learning platform for hearing-impaired students

1. Theoretical basis and research hypothesis

Based on the Outcome Based Assessment Theory (Weiss, 1997) and PDCA model (Parmenter, 2024), the research team implemented the WHIS platform and collected feedback from students, teachers and parents to evaluate its effectiveness. In addition, Multimedia Theory (Mayer, 2001) and the UTAUT Model of Technology Acceptance (Venkatesh et al., 2003) served as the basis for examining the impact of the platform on learning ability, motivation and accessibility of materials.

From this, the research team proposed three main hypotheses:
- H1: The WHIS online learning platform integrates multimedia technology to help deaf students improve their ability to acquire knowledge.

- H2: Interactive features such as gamification and sign language in WHIS increase learning motivation of deaf students.
- H3: WHIS improves accessibility and use of learning materials, especially in general education subjects that integrate sign language.

2. Experimental design and questionnaire

The experiment lasted 4 weeks at Hy Vong and Anh Duong School for the Deaf (HCMC), with 29 deaf students, 7 teachers and 18 parents. In the first phase, teachers guided students to use the system in class. In the second phase, students used it at home with the support of their parents to assess their self-learning ability.

To determine the results from the above 3 hypotheses, the team built a questionnaire consisting of two parts: demographic information and WHIS system evaluation with 12 main criteria, measured by a 5-level Likert scale. Hypothesis H1 was tested via "lesson clarity", "ease of use", "support for multimedia learning" and "ability to support learning". Hypothesis H2 is evaluated through"overall appeal", "activity/gameplay" and "interface design", "performance", "reuse intention".Hypothesis H3 is measured by the level"improve sign language", "learn English" and "learn History - Geography". The research team conducted semi-structured interviews to collect more in-depth feedback. Qualitative data were analyzed using a content analysis method.(Krippendorff, 2018)to identify factors that need improvement in the next phase.

3. Analysis results

3.1. Quantitative data analysis

The data collected from the survey was analyzed to provide a comprehensive view of the 54 users' feedback. The research team performed descriptive statistical analysis and received positive ratings on most criteria, with mean scores ranging from 3.72 to 4.24 on a 5-point scale."Ease of Use" (Mean = 3.72) and "Performance" (Mean = 3.76)achieve a satisfactory level, reflecting an intuitive and accessible system."Overall attractiveness" (Mean = 3.85, SD = 0.960) and "Interface design" (Mean = 3.92)shows that the platform is aesthetically pleasing and appropriate to the audience. The learning content, including"Learn English" (Mean = 4.24), "Learn History and Geography" (Mean = 4.12), along with"Activities/Games" (Mean = 4.21), is highly appreciated, affirming the effectiveness of teaching methods combining multimedia and gamification."Ability to support learning" (Mean = 4.15) and "Lesson clarity" (Mean = 4.12)shows that the system meets the needs of hearing-impaired students well."Intention to reuse" (Mean = 4.00)trended positively, demonstrating long-term application potential. Overall, the WHIS platform has proven effective in supporting inclusive education, but still needs to be adjusted to improve the user experience.

3.2. Qualitative data analysis

Qualitative data collected from semi-structured interviews and open-ended questions were analyzed using content analysis, focusing on three main themes that reflect core aspects of the system:

- Interface and ease of use: Users appreciated the intuitive and easy-to-use interface, especially teachers and parents. Some suggested improving the interface for younger students and those with limited cognitive abilities.

- **Learning support capabilities:**The system is highly appreciated for its learning support, especially sign language and English vocabulary, helping to improve communication skills and knowledge acquisition of hearing-impaired students.

- **Attractiveness and interactivity:**Users loved the games and interactive content, but suggested adding more rich activities. Some suggested adding personalized games to increase learning motivation.

4. Discussion

The quantitative results show that the system is highly appreciated, especially for its interactive features and lesson content. This is reinforced by the qualitative data, in which users emphasize the role of games and lessons integrating sign language in increasing learning efficiency. However, the criteria of "Ease of use" along with suggestions for improving the interface from users indicate that the user experience needs to be optimized to be more user-friendly. The results of study 3 confirm the following hypotheses:

Hypothesis (H1) is accepted: WHIS improves the learning ability of deaf students, as shown by the mean score of 4.15 on Learning Support Ability. Students appreciate the integration of sign language and illustrations, which makes the lecture easier to understand.

Hypothesis (H2) accepted: Gamification and sign language features increase learning engagement and motivation, as evidenced by the average score of 4.21 on Activities/Games. Additionally, users suggested further expansion of the game format to enhance the learning experience.

Hypothesis (H3) accepted: The WHIS platform does improve accessibility to learning materials, especially in general education subjects that integrate sign language. This is demonstrated by the mean scores of 4.12 for History and Geography, and 3.76 for English Vocabulary. However, feedback also indicated the need for additional visuals and videos to support more complex lessons.

5. Conclusion

Study 3 has successfully demonstrated the effectiveness of an online learning system integrating multimedia technology through experimental data. The results have confirmed the research hypotheses and provided specific recommendations for system improvement, thereby contributing to improving the quality of education and enhancing inclusion for deaf students in Vietnam.

V. General discussion

The research was implemented in three complementary phases to develop and evaluate an online learning platform for deaf students.study 1The development of a standardized scale assessing educational technology needs, barriers, and effectiveness revealed a high demand for nonverbal communication, content visualization, and technology integration.study 2Design and develop an online learning platform that integrates features such as sign language recognition, online learning of English, History, Geography, along with personalization and gamification to enhance communication and social integration.study 3Deploying the platform in a real-world environment with students, teachers, and parents demonstrated that the system effectively supports learning, increases engagement, and long-term usage intentions.long.

This research model inherits and expands solutions to support hearing-impaired students around the world, especially in the application of multimedia technology

and sign language.Lartz et al. (2008)emphasize the role of assistive technology in higher education, but do not yet integrate comprehensive online learning systems as the current study. Similarly,Abdallah & Fayoum (2016)Android platform development supports communication but does not address formal learning needs.Bell & Foiret (2020) Overview of the impact of assistive technology on learning performance, affirming the role of technology, but not yet developing a digital integration platform.

Research alsoSome limitations:The geographical scope is limited to Ho Chi Minh City, affecting representativeness; the experimental period is not enough to evaluate long-term effectiveness; the convenience sampling method reduces objectivity, especially for other areas. Future studies need to expand the scope, extend the experimental period and use more scientific sampling methods. This study not only inherits the effective factors from previous models but also expands by integrating multiple technologies on a single platform, supporting formal learning, sign language communication and social integration, creating a more comprehensive and socially equitable solution for deaf students in Ho Chi Minh City and aiming to expand nationwide.

VI. Contributions of the research

Research contributes boththeory and practiceIn theory, the study develops a standardized scale to assess the needs, barriers and effectiveness of educational technology for deaf students, overcoming research gaps in Vietnam. In practice, an online learning platform integrating multimedia and multi-functions has been designed and tested, providing a comprehensive digital transformation solution for inclusive education. The research results open up new directions for development in inclusive educational technology.

VII. General conclusion

The study provides a comprehensive view of the role of technology in inclusive education for deaf students in Vietnam. Three research phases are closely linked to develop and evaluate an effective online learning platform that meets the diverse needs of users. The study not only adds to the theory but also brings great practical value, contributing to promoting inclusion and equity in education, while creating a solid foundation for future research on optimizing educational technology.

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