# Augmented reality in the context of universal design for hearing impaired student

**Tidarat Luangrungruang, Gawalee Phatai**
Department of Computer, Faculty of Science and Technology, Sakon Nakhon Rajabhat University, Sakon Nakhon, Thailand

**Article Info**

***Article history:***

Received May 30, 2025
Revised Oct 26, 2025
Accepted Nov 23, 2025

***Keywords:***

Accessible learning
Augmented reality
Hearing impaired
Inclusive education
Universal design

**ABSTRACT**

Advancing equal rights and prohibiting discrimination based on disability are essential to achieving social equity. Education serves as a vital mechanism in this effort, particularly through inclusive practices that support diverse learners. Sakon Nakhon Rajabhat University advances these values by admitting students with disabilities, including those with hearing impairments, and by fostering accessible learning environments. This study presents the development of an augmented reality (AR) application, designed according to universal design (UD) principles, to enhance learning for students with hearing impairments. The AR technology integrates real and virtual elements to create an engaging and interactive educational experience. Evaluation results indicate a high level of effectiveness, with the assessment dimension receiving the highest mean score ($\bar{x} = 4.87, SD = 0.35$), and overall effectiveness rated similarly ($\bar{x} = 4.78, SD = 0.42$). User satisfaction was also rated at a very high level across all aspects ($\bar{x} = 4.67, SD = 0.54$). These findings highlight the potential of AR technology, when guided by inclusive design principles, to improve learning outcomes for students with hearing impairments.



***Corresponding Author:***

Tidarat Luangrungruang
Department of Computer, Faculty of Science and Technology, Sakon Nakhon Rajabhat University
Sakon Nakhon, Thailand
Email: tidarat@snru.ac.th

## 1. INTRODUCTION

According to the World Health Organization (WHO), over 5% of the global population—more than 360 million people—experience hearing loss, with the majority residing in low- and middle-income countries [1]. Education for individuals who are deaf or hard of hearing (DHH) presents unique challenges, particularly in early childhood, when acquiring language and communication skills is more complex due to interactions with family members and others who may not be hearing-impaired [2]. Education is universally recognized as a fundamental human right, and no individual should face discrimination based on disability or physical condition. Ensuring equal access to education plays a critical role in fostering social equity and contributing to national development. In line with this vision, the Sakon Nakhon Provincial Development Plan (2023–2027) highlights the need for inclusive education for people with disabilities, promoting awareness of legal rights and access to state-supported services.

Sakon Nakhon Rajabhat University has aligned its strategic educational goals with inclusive principles by implementing initiatives that support students with disabilities. These efforts ensure that all students with disabilities have equitable access to resources and opportunities to reach their full potential. A key component of this strategy is the development of accessible and adaptive learning media, which plays a vital role in enhancing educational outcomes. Augmented reality (AR) is a digital technology that merges real and virtual environments through software and interactive devices. Over the past 25 years, AR has gained widespread application in education due to its ability to increase learner engagement, enjoyment, and academic performance [3]. A literature review of 1,694 scholarly works identified 26 studies published between 2006 and 2020 that focused specifically on the use of AR for students with hearing impairments. Of these, approximately 60% employed marker-based AR systems, reporting positive impacts on student motivation, interactivity, and learning outcomes [1].

The learning process of students with hearing impairments often affects their proficiency in both language and mathematical reasoning. As a result, educational materials utilizing AR have been developed to support these learners [4]. Although emerging technologies have the potential to create diverse methods and models of learning, the impact of the internet of things (IoT) on the education of students with hearing impairments remains poorly understood. Learning IoT concepts poses unique challenges, particularly because such content is difficult to translate and communicate through sign language [5]. Therefore, specialized instructional strategies are necessary for this group of learners. Effective learning for students with hearing impairments requires strong language comprehension and accurate perceptual understanding, which leads to a distinctive reliance on visual processing. Despite the promise of AR in enhancing learning outcomes, its application in computer science education for hearing-impaired students remains limited. To address this gap, a new AR-based learning tool has been developed following the principles of universal design (UD). This initiative aims not only to enhance learning outcomes for students with hearing impairments but also to offer meaningful benefits to other learners interested in the subject.

The aforementioned research findings highlight the potential of utilizing three-dimensional AR technology to enhance the dissemination of knowledge in computer science courses. AR technology offers opportunities to increase learner engagement and facilitate the effective communication of course content. However, the application of AR in computer science education for students with hearing impairments remains limited at Sakon Nakhon Rajabhat University. To address this gap, an AR-based learning tool has been developed based on the principles of UD. The objective is to create instructional media that improve learning efficiency for students with hearing impairments, while also providing educational benefits for other learners interested in the subject.

## 2. METHOD

This study focuses on the development of an AR application designed to support hearing-impaired students in learning foundational computer concepts. The methodology integrates three core frameworks: sign language principles, AR technology, and universal design for learning (UDL).

### 2.1. Sign language as a foundation for content design

Sign language, the primary mode of communication within DHH communities, incorporates a rich combination of hand movements, facial expressions, and spatial body positioning [6], [7]. It can be conceptualized as a three-dimensional visual language [8], ranging from informal context-specific gestures to standardized national sign languages [9]. In this study, sign language serves as the basis for content representation, ensuring accessibility and clarity of information within the AR environment.

### 2.2. Integration of augmented reality

AR technology enhances real-world environments by overlaying virtual elements that can be interactively processed alongside physical reality [10]. In the context of education, AR has been shown to improve student engagement, motivation, and learning outcomes [11]. Marker-based AR was applied in this study to facilitate the presentation of sign language content and interactive learning components [12].

Over the past decade, AR has emerged as a significant trend in educational research [13]–[15]. Studies have highlighted AR's potential to enhance learning, particularly in science, technology, mathematics, and language education [13], [15]. In secondary education, AR has been reported to improve students' interest, attitudes, classroom engagement, collaboration, and self-directed learning [13], [15]. Moreover, AR contributes to more dynamic and meaningful learning experiences by actively involving students in the learning process. Research indicates that the most effective outcomes are achieved when AR is integrated into collaborative, classroom-based learning environments [14].

In addition, AR has been applied to support sign language communication across various educational levels from primary [16]–[18] and secondary education [19], to higher education [20], [21]. These applications have been particularly effective in enhancing physical and cognitive skills among students with special needs, including those with hearing impairments [22].

### 2.3. Application of universal design and universal design for learning

The development process adheres to UD principles, promoting inclusivity by making systems accessible to all users. In education, UDL extends this approach by providing flexible methods for presenting information, engaging learners, and assessing performance, thereby addressing diverse needs and removing learning barriers [23]. By incorporating UDL, the AR tool was designed to support hearing-impaired students while remaining valuable for a broader audience. The methodology integrates linguistic, technological, and pedagogical strategies, combining AR with sign language content. This approach enhances comprehension for hearing-impaired learners and offers a scalable, adaptable solution for inclusive education.

### 2.4. Development and evaluation of the AR application

The AR application was systematically developed using UDL principles to support hearing-impaired students in the information technology curriculum. A needs analysis, including interviews with students and consultations with special education instructors, identified key learning challenges. Core curriculum content was then adapted and translated into Thai sign language in collaboration with certified interpreters, incorporating visual representations, technical terminology, and culturally appropriate gestures to enhance AR-based interaction.

A marker-based AR environment was created using Unity 3D and the Vuforia SDK, allowing students to interact with 3D objects and synchronized sign language video overlays. The interface prioritized visual clarity, intuitive navigation, and device compatibility. Expert reviewers evaluated the application, and subsequent testing with hearing-impaired students informed usability and engagement improvements.

To assess effectiveness and user satisfaction, 26 hearing-impaired students participated in pre- and post-tests, a 5-point Likert questionnaire, and interviews. Quantitative data were analyzed using descriptive statistics and paired t-tests, while qualitative feedback was thematically examined. In line with UDL principles, the application addressed representation through multimedia content and sign language support, expression through user feedback mechanisms, and engagement via interactive 3D environments. These strategies collectively enhanced accessibility, learning outcomes, and motivation, as summarized in Table 1. Table 1 illustrates the application of UDL within the development process of the AR-based educational tool. The UDL framework was implemented through multiple modes of content representation, opportunities for learners to express feedback, and active engagement using AR tailored to hearing-impaired students.

Table 1. Application of UDL

| Universal design for learning | Implementation procedures |
|---|---|
| Representation | – Multimedia content such as websites, videos, still images, and text<br>– Thai sign language and symbolic representations |
| Expression | – Satisfaction surveys and feedback forms for collecting opinions and suggestions |
| Engagement | – Utilization of augmented reality applications designed specifically for deaf and hard of hearing learners using universal design principles |

### 2.5. Hearing impairment and educational challenges

Hearing impairment refers to the condition in which an individual experiences limitation in performing daily activities or participating in social engagements due to auditory dysfunction. This is characterized by a hearing loss of 90 decibels (dB) or more in the better ear, as measured at the frequencies of 500 Hz, 1,000 Hz, and 2,000 Hz. Such a degree of hearing loss significantly affects an individual's ability to access auditory information.

Within the deaf community, sign language is the primary mode of communication and comprises body movements, facial expressions, hand gestures, and body positioning, all of which are conveyed in three-dimensional space [6], [7], [24]. These range from informal, context-specific gestures to fully standardized national sign languages [8], [9]. In Thailand, Thai sign language (TSL) is widely disseminated through television networks, where it is used for content interpretation, thereby increasing public recognition and awareness of sign language [25].

Deaf children typically rely on a combination of sign language and lip-reading for communication. However, reading plays a central role in their learning process [26], and unlike hearing individuals who associate letters with sounds, deaf learners tend to memorize visual characters. Consequently, when writing, they often construct short and simple sentences with limited structural complexity and lack transitional elements. Grammatical errors are also more frequent [27], [28].

To address these challenges, the AR application developed in this study was designed based on UD principles and includes TSL, written content, audio elements, and 3D models to comprehensively support the learning experience of hearing-impaired students.

This study focuses on the development of an AR learning tool for students with hearing impairments, designed in accordance with the principles of UDL. Prior to data collection, the researcher was required to complete training and obtain certification in research ethics for studies involving human participants. The development process was carried out in several structured phases. A summary of this process is presented in Figure 1.

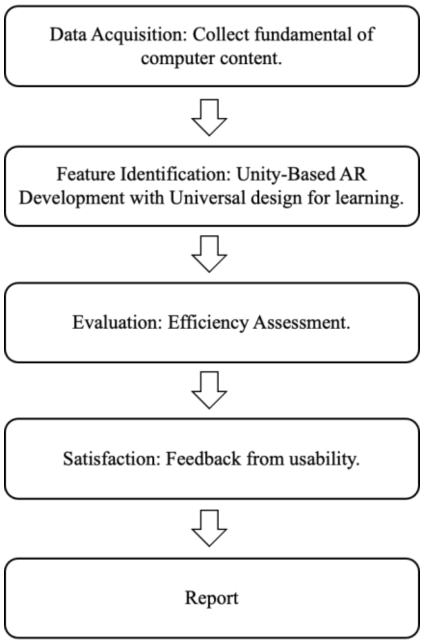


Figure 1. Development and evaluation process of the AR application based on UDL

This study followed a structured development process to create an AR application tailored for hearing-impaired students. Core computer content was first collected, incorporating principles of UDL, TSL interpretation, and essential resources for AR development. Using Unity, interactive educational features were integrated following UDL guidelines and certified TSL standards. The application's efficiency was evaluated by a panel of five experts in computer education and sign language, whose feedback informed system refinements. Learning outcomes were assessed through pre- and post-tests, with relative gain and difference scores calculated to measure student progress. Additionally, 26 participants provided usability feedback to enhance satisfaction and effectiveness. Results, summarized graphically, demonstrated notable improvements in learning performance and comprehension, confirming the AR application's potential as an effective educational tool for DHH learners.

## 3. RESULTS AND DISCUSSION

This section presents the outcomes from the study and development of the AR application for hearing-impaired students, designed by UD principles.

### 3.1. Efficiency evaluation results

The system's efficiency was evaluated by five experts using a five-level rating scale. The evaluation focused on three primary aspects: usability, system performance, and evaluation mechanism. The results of the assessment are presented in Table 2.

Table 2. Results of the expert evaluation of the AR application's performance

| Evaluation aspect | $\bar{x}$ | $SD$ | Evaluation level |
|---|---|---|---|
| Usability | 4.67 | 0.43 | Very good |
| System performance | 4.87 | 0.35 | Very good |
| Evaluation mechanism | 4.80 | 0.41 | Very good |
| Overall average score | 4.78 | 0.42 | Very good |

As shown in Table 2, the overall evaluation of the AR system designed for hearing-impaired students demonstrated a very high level of efficiency ($\bar{x} = 4.78, SD = 0.42$). Among the three assessed dimensions, the system performance received the highest mean score ($\bar{x} = 4.87, SD = 0.35$), indicating a particularly strong endorsement of the system's evaluation framework. The usage of the developed AR application by hearing-impaired students is depicted in Figure 2, illustrating the integration of sign language support, interactive 3D content, and accessible user interface features designed in accordance with UDL principles.

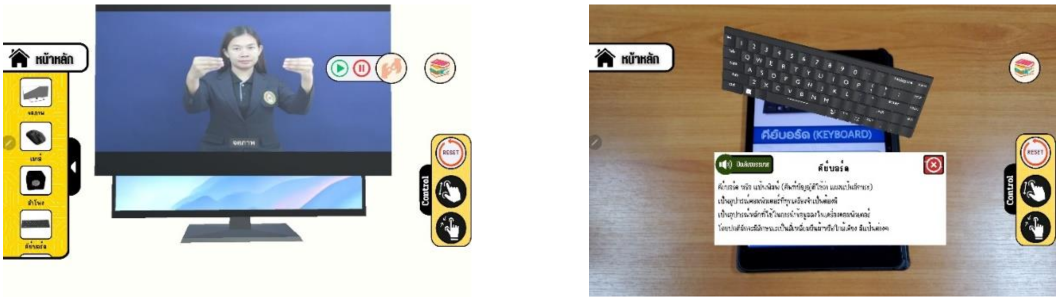


Figure 2. Application usage

### 3.2. User satisfaction results

To evaluate user satisfaction, a total of 26 students with hearing impairments participated in the assessment of the developed AR application. The evaluation emphasized key dimensions including usability, accessibility, and the overall learning experience provided by the system. The results of the satisfaction assessment are summarized in Table 3.

Table 3. Summary of user satisfaction scores for the AR application

| Satisfaction aspect | $\bar{x}$ | SD | Evaluation level |
|---|---|---|---|
| Overall satisfaction score | 4.67 | 0.54 | Very good |

As indicated in Table 3, the overall satisfaction level reported by the participants was at a very high level ($\bar{x} = 4.67, SD = 0.54$). These results suggest that the AR application, which was developed based on UDL principles, effectively addressed the needs of students with hearing impairments, especially in terms of content presentation and interaction.

To measure the effectiveness of the application in enhancing learning outcomes, pre-test and post-test evaluations were conducted. Figure 3 presents a comparative analysis of test scores before and after the use of the AR tool. The X-axis represents the 26 participating students, while the Y-axis displays the scores in percentage format (maximum score = 100%). The results reveal a noticeable improvement in post-test scores, indicating a positive impact of the AR application on learners' understanding of computer hardware concepts.

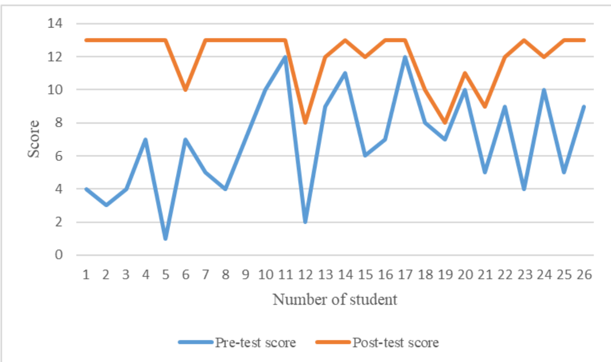


Figure 3. Comparison of pre-test and post-test scores

In addition, Figure 4 illustrates the analysis of score differences and relative gain scores between the pre-test and post-test results. These metrics provide further evidence of the educational value of the AR application, highlighting its effectiveness in supporting knowledge retention and comprehension. The interpretation of relative gain scores, derived from the difference between pre-test and post-test results, may be affected by the ceiling effect, wherein high-achieving students score near the maximum on the pre-test, thus limiting observable improvement in the post-test. For instance, in this study, the test had a maximum score of 13 points. Student 5 scored 1 point before and 13 points after, while student 11 scored 12 and 13 points, respectively, both yielding a relative gain of 100%. However, the actual learning gain of student 5 is more substantial, although this is not reflected in the relative gain due to the scoring ceiling. This limitation suggests the need to consider individual learner profiles in interpreting results. Despite this, the overall average relative gain was 82.57, indicating a very high level of learning improvement, with 65.38% of students showing a very high gain, 15.38% high gain, 15.38% moderate gain, and 3.85% low gain, demonstrating the effectiveness of the AR application for hearing-impaired learners. The comparison of pre- and post-learning achievements of students using the AR application was analyzed using a dependent samples t-test, as summarized in Table 4.

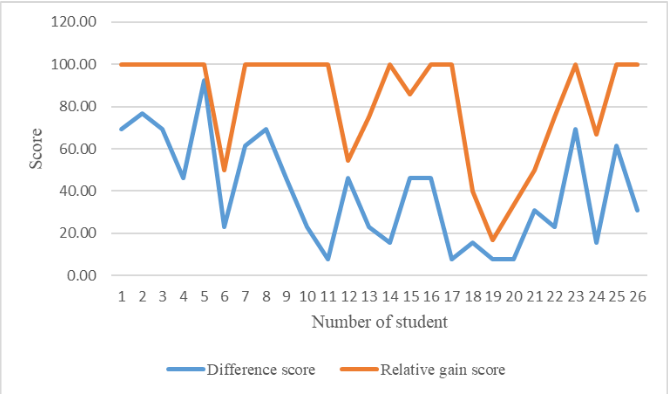


Figure 4. Comparison of difference scores and relative gain scores

Table 4. Comparison of pre- and post-learning achievement scores using AR application

| Testing | $n$ | $\bar{x}$ | SD | t-Test |
|---|---|---|---|---|
| Pre-test | 26 | 6.85 | 2.98 | 8.01 |
| Post-test | 26 | 12.00 | 1.59 | |

To evaluate the effectiveness of the developed e-learning materials, a dependent samples t-test was conducted to compare students' learning achievement before and after using the platform. As shown in Table 4, the mean pre-test score of 26 hearing-impaired students was 6.85 ($SD = 2.98$), while the mean post-test score increased significantly to 12.00 ($SD = 1.59$). The calculated t-value of 8.01 exceeded the critical value of 1.71 at the 0.05 significance level, indicating a statistically significant improvement in post-test scores ($p < 0.05$). These findings suggest that the AR application had a substantial positive effect on students' academic performance.

Furthermore, the analysis of relative gain scores revealed notable individual learning progress. Although some students demonstrated high pre-test scores, which limited the margin for post-test improvement due to ceiling effects, most participants showed substantial relative gains. For instance, students with low initial performance were able to achieve full scores post-instruction, reflecting strong learning development. The ability to access and review content repeatedly, including sign language vocabulary related to computer hardware, likely contributed to these outcomes. The results support the effectiveness of AR application in enhancing educational accessibility and learning achievement for hearing-impaired students.

### 3.3. Discussion

The development of the AR application for hearing-impaired students, guided by UD principles, enabled the use of a mobile-based learning tool. Users could explore computer hardware through interactive 3D models in an AR environment, allowing 360-degree visualization accompanied by audio narration, Thai subtitles, and TSL interpretation all of which could be toggled on or off based on user preference. The evaluation of the AR application was conducted across three dimensions: usability, system performance, and evaluation mechanism. The expert review, involving five specialists in relevant fields, indicated that the overall efficiency of the AR application was rated at a very high level ($\bar{x} = 4.78, SD = 0.42$).

In terms of user satisfaction, the evaluation involved 26 hearing-impaired students, whose feedback highlighted strong agreement with the application's alignment with learning objectives, logical sequencing of content presentation, and the appropriate layout and organization of on-screen components. The overall user satisfaction rating was also at a very high level ($\bar{x} = 4.67, SD = 0.54$), indicating the AR application's success in meeting the needs of hearing-impaired learners and providing an accessible and engaging learning experience.

## 4. CONCLUSION

The literature review and prior studies provided a robust foundation for defining the scope and conceptual framework of an AR learning application designed for students with hearing impairments. Developed in alignment with the principles of UDL, the tool supports diverse learning needs and fosters equitable access to educational content. The AR application enables learners to engage with virtual three-dimensional models of computer hardware and offers multiple modes of information delivery, including optional audio narration, subtitles, and TSL. This multimodal design allows learners to access and review content flexibly and in accordance with their individual preferences and pace. By reducing learning barriers and promoting inclusivity, the application contributed to measurable improvements in educational outcomes, such as increased test scores and academic development.

User feedback indicated high levels of satisfaction, particularly in relation to the application's usability, the quality of its 3D visualizations, and the integration of TSL as a core communication method. Given its demonstrated success, the application presents strong potential for expansion into additional subject areas and integration with emerging educational technologies. Furthermore, the design framework could be adapted to support other learner groups, such as students with speech impairments or students with hearing impairments who use another sign language.

## ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to all respondents who kindly completed the questionnaires, as well as to the students and experts from Sakon Nakhon Rajabhat University who participated in this study. Special thanks are extended to the Department of Computer, Faculty of Science and Technology, Sakon Nakhon Rajabhat University, for providing the research facilities and equipment used in this work. This research was partially supported by the Research and Development Institute, Sakon Nakhon Rajabhat University, Sakon Nakhon, Thailand.

## FUNDING INFORMATION

This work was funded by the Research and Development Institute, Sakon Nakhon Rajabhat University, Sakon Nakhon, Thailand.

## AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

| Name of Author | C | M | So | Va | Fo | I | R | D | O | E | Vi | Su | P | Fu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tidarat Luangrungruang | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | | ✓ | |
| Gawalee Phatai | | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | |

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

## CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

## DATA AVAILABILITY

Data are available from the corresponding author upon reasonable request.

## REFERENCES


[1] N. Fernandes, A. J. M. Leite Junior, E. Marçal, and W. Viana, "Augmented reality in education for people who are deaf or hard of hearing: a systematic literature review," *Universal Access in the Information Society*, vol. 23, no. 3, pp. 1483–1502, Aug. 2024, doi: 10.1007/s10209-023-00994-z.

[2] J. Joy, K. Balakrishnan, and M. Sreeraj, "SiLearn: an intelligent sign vocabulary learning tool," *Journal of Enabling Technologies*, vol. 13, no. 3, pp. 173–187, Aug. 2019, doi: 10.1108/JET-03-2019-0014.

[3] J. Garzón, "An overview of twenty-five years of augmented reality in education," *Multimodal Technologies and Interaction*, vol. 5, no. 7, p. 37, 2021, doi: 10.3390/mti5070037.

[4] A. Hasanah, Y. S. Kusumah, and K. Rahmi, "Rounding-augmented reality book and smartphone for deaf students in achieving basic competence," in *Journal of Physics: Conference Series*, 2020, vol. 1521, no. 3, p. 32064, doi: 10.1088/1742-6596/1521/3/032064.

[5] M. Alrashidi, "Synergistic integration between internet of things and augmented reality technologies for deaf persons in e-learning platform," *Journal of Supercomputing*, vol. 79, no. 10, pp. 10747–10773, Jul. 2023, doi: 10.1007/s11227-022-04952-z.

[6] W. C. Stokoe and M. Marschark, "Sign language structure: An outline of the visual communication systems of the American deaf," *Journal of Deaf Studies and Deaf Education*, vol. 10, no. 1, pp. 3–37, Jan. 2005, doi: 10.1093/deafed/eni001.

[7] S. K. Liddell, *American sign language*. Mouton De Gruyter, 1980.

[8] A. Duranti, *A Companion to Linguistic Anthropology*. MA, USA: Wiley, 2007.

[9] U. Zeshan, "Sign Languages of the World," in *Encyclopedia of Language & Linguistics*, K. Brown, Ed. Oxford: Elsevier, 2006, pp. 358–365.

[10] V. Raja and P. Calvo, "Augmented reality: An ecological blend," *Cognitive Systems Research*, vol. 42, pp. 58–72, May 2017, doi: 10.1016/j.cogsys.2016.11.009.

[11] M. Kesim and Y. Ozarslan, "Augmented Reality in Education: Current Technologies and the Potential for Education," *Procedia - Social and Behavioral Sciences*, vol. 47, pp. 297–302, 2012, doi: 10.1016/j.sbspro.2012.06.654.

[12] N. Aottiwerch and U. Kokaew, "Design computer-Assisted learning in an online Augmented Reality environment based on Shneiderman's eight Golden Rules," in *Proceedings of the 2017 14th International Joint Conference on Computer Science and Software Engineering, JCSSE 2017*, Jul. 2017, pp. 1–5, doi: 10.1109/JCSSE.2017.8025926.

[13] F. Arici, P. Yildirim, Ş. Caliklar, and R. M. Yilmaz, "Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis," *Computers and Education*, vol. 142, p. 103647, Dec. 2019, doi: 10.1016/j.compedu.2019.103647.

[14] J. Garzón, J. Pavón, and S. Baldiris, "Systematic review and meta-analysis of augmented reality in educational settings," *Virtual Reality*, vol. 23, no. 4, pp. 447–459, Dec. 2019, doi: 10.1007/s10055-019-00379-9.

[15] M. B. Ibáñez and C. Delgado-Kloos, "Augmented reality for STEM learning: A systematic review," *Computers and Education*, vol. 123, pp. 109–123, Aug. 2018, doi: 10.1016/j.compedu.2018.05.002.

[16] S. Al-Megren and A. Almutairi, "Analysis of user requirements for a mobile augmented reality application to support literacy development amongst hearing-impaired children," *Journal of Information and Communication Technology*, vol. 18, no. 1, pp. 97–121, 2019, doi: 10.32890/jict2019.18.1.8283.

[17] S. Deb, Suraksha, and P. Bhattacharya, "Augmented Sign Language Modeling(ASLM) with interaction design on smartphone - An assistive learning and communication tool for inclusive classroom," *Procedia Computer Science*, vol. 125, pp. 492–500, 2018, doi: 10.1016/j.procs.2017.12.064.

[18] B. S. Parton, "Glass Vision 3D: Digital Discovery for the Deaf," *TechTrends*, vol. 61, no. 2, pp. 141–146, Mar. 2017, doi: 10.1007/s11528-016-0090-z.

[19] A. Ioannou and V. Constantinou, "Augmented reality supporting deaf students in mainstream schools: Two case studies of practical utility of the technology," in *Advances in Intelligent Systems and Computing*, vol. 725, Springer, 2018, pp. 387–396.

[20] N. Hirabayashi, N. Fujikawa, R. Yoshimura, and Y. Fujisawa, "Development of learning support equipment for sign language and fingerspelling by mixed reality," in *ACM International Conference Proceeding Series*, May 2019, pp. 1–6, doi: 10.1145/3325291.3325373.

[21] S. Alkhalifa and M. Al-Razgan, "Enssat: wearable technology application for the deaf and hard of hearing," *Multimedia Tools and Applications*, vol. 77, no. 17, pp. 22007–22031, Sep. 2018, doi: 10.1007/s11042-018-5860-5.

[22] J. J. Ojeda-Castelo, J. A. Piedra-Fernandez, L. Iribarne, and C. Bernal-Bravo, "KiNEEt: application for learning and rehabilitation in special educational needs," *Multimedia Tools and Applications*, vol. 77, no. 18, pp. 24013–24039, Sep. 2018, doi: 10.1007/s11042-018-5678-1.

[23] S. a Spencer, "Universal Design for Learning: Assistance for teachers in today's inclusive classrooms.," *Interdisciplinary Journal of Teaching & Learning*, vol. 1, no. 1, pp. 10–22, 2011.

[24] D. D. F. Guilhermino Trindade, C. Guimares, D. R. Antunes, L. Sánchez Garcia, R. A. Lopes Da Silva, and S. Fernandes, "Challenges of knowledge management and creation in communities of practice organisations of Deaf and non-Deaf members: Requirements for a Web platform," *Behaviour and Information Technology*, vol. 31, no. 8, pp. 799–810, 2012, doi: 10.1080/0144929X.2011.650712.

[25] A. M. Nonaka, "(Almost) everyone here spoke Ban Khor Sign Language-Until they started using TSL: Language shift and endangerment of a Thai village sign language," *Language and Communication*, vol. 38, no. 1, pp. 54–72, 2014, doi: 10.1016/j.langcom.2014.05.005.

[26] Y. Zhao, P. Sun, R. Xie, H. Chen, J. Feng, and X. Wu, "The relative contributions of phonological awareness and vocabulary knowledge to deaf and hearing children's reading fluency in Chinese," *Research in Developmental Disabilities*, vol. 92, p. 103444, 2019, doi: 10.1016/j.ridd.2019.103444.

[27] A. Webster, *Deafness, development and literacy*. London: Methuen & Co. Ltd, 2017.
[28] H. R. Myklebust, *The psychology of deafness: sensory deprivation, learning, and adjustment*, 2nd ed. New York: Grune and Stratton, 1964.

## BIOGRAPHIES OF AUTHORS

**Tidarat Luangrungruang** is currently working as an Assistant Professor in the Department of Computer, Faculty of Science and Technology, at Sakon Nakhon Rajabhat University (SNRU). She received her Ph.D. in information technology from Khon Kaen University. Her research interests include educational data analytics and behavioral intention. She can be contacted at email: tidarat@snru.ac.th.

**Gawalee Phatai** is currently working as an Assistant Professor in the Department of Computer, Faculty of Science and Technology, at Sakon Nakhon Rajabhat University (SNRU). She received her Ph.D. in information technology from Khon Kaen University. Her research interests include machine learning, neural networks, data science, and optimization algorithms. She can be contacted at email: gawalee@snru.ac.th.