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Inclusive Learning Innovation for Deaf Students Using Sign Language Through Augmented Reality Technology

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Abstract: This study aims to develop Augmented Reality (AR)-based learning media to enhance sign language learning skills for deaf students in the Special Education Study Program at Universitas PGRI Argopuro Jember. The research method employed is the ADDIE development model, which consists of the stages of Analysis, Design, Development, Implementation, and Evaluation. The analysis phase revealed that the sign language learning process still relies on conventional methods without the support of innovative media, indicating the need for an interactive technology-based solution such as AR. The developed media is an AR application featuring 3D models of hand and finger movements adapted from the SIBI Dictionary, designed based on VISUALS principles to ensure ease of use, accuracy, and precision in learning. Validation results from media experts indicated a feasibility percentage of 89.37%, while material experts rated it at 86.66%, both categorized as highly feasible. The application was implemented with 11 deaf students, showing an average usage effectiveness of 94.54%, along with positive responses regarding ease of use, information accuracy, and flexibility in learning sign language anytime and anywhere. Evaluation was conducted using a Likert-scale questionnaire to measure the application's effectiveness. The findings demonstrate that AR-based learning media is highly effective in improving sign language comprehension and providing an inclusive learning experience for deaf students. This application is expected to serve as an innovative alternative learning medium in higher education to support technology-based inclusive education.

Keywords: Inclusive learning, Deaf students, Sign language, Augmented reality, ADDIE Model.

INTRODUCTION

Inclusive education is a global commitment aimed at ensuring that all individuals, including persons with disabilities, have equal opportunities to access quality education (UNESCO, 2020). In Indonesia, inclusive education policies have encouraged educational institutions to provide adaptive and accommodative services for students with special needs, including deaf students. However, the availability of learning media tailored to the needs of deaf students remains very limited, especially in mastering Sign Language, which serves as their primary means of communication (Juntak et al., 2023).

Sign Language is a complex form of visual communication that relies on hand movements, finger positions, facial expressions, and body orientation to convey meaning. In higher education, Sign Language instruction is still predominantly delivered through conventional methods, such as direct demonstrations by lecturers, without the support of adaptive technology-based learning media (Setyono et al., 2024). This presents a significant challenge for deaf students, particularly in reinforcing their understanding and mastery of Sign Language independently or outside the classroom. This situation highlights a gap between the learning needs of deaf students and the availability of innovative, technology-based learning resources.

Along with the advancement of the Industrial Revolution 4.0 and the demands of the Society 5.0 era, the integration of technology in education has become increasingly relevant to enhance the quality and accessibility of learning.

One technology with significant potential to improve learning effectiveness is Augmented Reality (AR). AR technology enables the integration of the real world with virtual 3D objects in real time, creating a more interactive and immersive learning experience (Garzón & Acevedo, 2019). The use of AR in education has been proven to increase motivation, participation, and conceptual understanding, particularly for learners with visual and kinesthetic learning styles, such as deaf students (Buliali et al., 2021).

Previous studies have revealed the benefits of AR in supporting learning for students with special needs. For instance, research by (Cavus et al., 2021) demonstrated that AR is effective in enhancing vocabulary mastery for students with developmental disabilities. Additionally, (Hapsari et al., 2023) emphasized the importance of the accuracy of 3D object design in the development of AR-based learning media, especially for Sign Language, to ensure that the movements displayed align with standards and are easily understood by users. Nevertheless, in Indonesia, the application of AR in Sign Language learning at the higher education level remains very limited, both in terms of research and practical development.

This study offers significant novelty in the development of learning media for deaf students in higher education. The first novelty lies in the integration of AR technology in Sign Language learning at the tertiary level, which has previously been more commonly developed for primary or early education. The media developed in this study utilizes specially designed 3D models equipped with rigging techniques to ensure that the hand and finger movements displayed accurately reflect the authentic gestures found in the Indonesian Sign System Dictionary (SIBI). This directly addresses the challenge of visual accuracy, which has often been a limitation in previous technology-based Sign Language learning media.

In addition, this research presents a unique development approach by employing the ADDIE model, which systematically includes the stages of Analysis, Design, Development, Implementation, and Evaluation (Fransiska et al., 2025; Adeoye et al., 2024). This model ensures that the resulting product is not only technically effective but also aligned with user needs and the relevant curriculum. The study also strengthens its empirical aspect by directly testing the application's effectiveness with deaf students at Universitas PGRI Argopuro Jember in enhancing their understanding of Sign Language.

Another novelty produced by this research is the application of the VISUALS principle in the design of the learning media, ensuring that the developed application is Visible, Interesting, Simple, Useful, Accurate, Legitimate, and Structured. This approach has not been widely adopted in the development of AR media for Sign Language in Indonesia, making it a valuable contribution to the advancement of both theory and practice in technology-based education. The media developed in this study is intended not only for deaf students but also for general students or educators who wish to learn Sign Language in a visual and interactive manner.

Thus, this research contributes both theoretically and practically to the development of technology-based inclusive learning innovations in Indonesia. The resulting media is expected to serve as an effective alternative for strengthening Sign Language education in higher education, while also providing a model for the development of other learning media for students with special needs in the era of digital transformation.

METHODS

This research employed the ADDIE model approach, selected for its advantages in providing a systematic and well-structured framework that facilitates the researcher in carrying out each development stage sequentially, from needs identification to final evaluation (Satyawan, 2025). The following describes how the ADDIE model was applied;

1. Analysis

This stage involved conducting a study to explore the learning needs and objectives related to Sign Language education for students with hearing impairments at Universitas PGRI Argopuro Jember. The analysis covered the characteristics of the students, the learning environment, and various obstacles encountered during the Sign Language learning process. In addition, the potential use of Augmented Reality (AR) technology was explored as a supportive tool to enhance learning effectiveness.

2. Design

The design phase focused on developing a blueprint for the product, specifically an Augmented Reality-based learning media for Sign Language tailored to deaf students. This phase is critical for developing and refining the

learning system or activity. The main focus of the instructional planning was on integrating Sign Language with AR technology. This stage included the formulation of clear and measurable learning objectives to be achieved through the use of AR. Moreover, an AR-based learning scenario was designed to enable users to interact visually with various symbols and movements in Sign Language. The user interface was also designed to be intuitive, facilitating optimal comprehension of Sign Language.

3. Development

The development phase concentrated on creating AR content relevant to Sign Language materials. This involved producing visual representations of alphabetic signs in the form of three-dimensional (3D) objects or animations accessible via AR-enabled devices. The content was also equipped with clear instructions and guidelines to help users easily understand and learn Sign Language.

4. Implementation

The implementation stage involved testing the developed product by applying the AR-based learning materials with deaf students. Students were ensured access to the AR content using compatible devices such as smartphones or tablets. Easy-to-understand user guides and technical support were provided to ensure smooth usage of the application.

5. Evaluation

The final phase focused on evaluating the effectiveness of AR usage in the Sign Language learning process. Feedback from participants was collected to understand their learning experiences with AR. The evaluation results served as a basis for improving and further developing AR applications in future Sign Language education initiatives.

A descriptive data analysis was conducted to assess the effectiveness of using Augmented Reality (AR) as an alternative interactive learning medium for Sign Language, including the level of student satisfaction with the features and the accuracy of the 3D Sign Language models (BISINDO) presented. The study involved deaf students at Universitas PGRI Argopuro Jember, with a research population consisting of 11 students with hearing impairments (deaf).

The data collection technique employed by the researcher utilized a Likert scale by distributing questionnaires containing statements ranging from "strongly agree" to "disagree" to the deaf students. This aimed to determine the effectiveness level of AR as an alternative interactive learning medium for Sign Language. To measure this, the highest score (Y) and the lowest score (X) for each assessment item were identified using the following formula:

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Y = Highest Likert score × Number of respondents
X = Lowest Likert score × Number of respondents

before completing the interpretation, it is necessary to calculate the interval (range) and the percentage interpretation to determine the assessment level using the score percentage interval method, as follows:
Index % = Total Score x 100
here are the criteria for score interpretation based on intervals:

Table 1. Score Category Interpretation

No	Percentage Interval Values	Description
1	0 % - 19.99 %	Strongly Disagree / Very Inadequate
2	20 % - 39.99 %	Disagree / Somewhat Disagree
3	40 % - 59.99 %	Fair / Neutral
4	60 % - 79.99 %	Agree / Good / Like
5	80 % - 100 %	Strongly Agree (Agree / Very Good)

Source: (Andriyani & Buliali, 2021)

This study employed a questionnaire consisting of several indicators used to measure the effectiveness of an application. There were 3 questions designed for teachers and 4 questions for students, with response options including: "Strongly Agree (SA)," "Agree (A)," "Fair (F)," "Disagree (D)," and "Strongly Disagree (SD)".

FINDINGS AND DISCUSSION

The result of this research is a learning media in the form of an Augmented Reality (AR)-based application for Sign Language learning, designed for deaf students in the Special Education Study Program at Universitas PGRI Argopuro Jember. The development procedure used in this study followed the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The detailed stages are as follows:

1. Analysis

Data in this study were obtained through in-depth interviews with deaf students and lecturers who teach Sign Language courses in the Special Education Study Program at Universitas PGRI Argopuro Jember. The interview results revealed that most lecturers still rely on conventional teaching methods without utilizing supportive learning media, particularly for delivering Sign Language material to deaf students. This indicates a limitation in the use of innovative educational technologies. Moreover, it was found that many lecturers lack sufficient knowledge or understanding of Augmented Reality (AR)-based learning media, even though this technology holds great potential in creating a more engaging, interactive, and easily comprehensible learning environment for students with hearing impairments. AR can serve as an effective tool to reinforce visual conceptual understanding, which is essential in learning Sign Language. Additionally, the analysis included a review of the curriculum used by the Special Education Study Program, particularly in formulating the Graduate Learning Outcomes, subject matter, and learning outcome indicators. This analysis is crucial to ensure that the curriculum is genuinely responsive to the needs of deaf students and supports the optimal development of their competencies.

2. Design

The design of the 3D objects in the application was based on the essential aspects of Sign Language demonstrations. In Sign Language, the most critical elements are the positions of the hands and the shapes of the fingers. Therefore, the 3D objects developed in this study include models of human arms, hands, and fingers. Several prototype designs were created to transform Sign Language codes into 3D models, as described below.

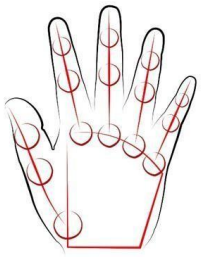

Figure 1. 3D Hand Model Design

Figure 1. illustrates the prototype design for modeling the shape of the hand and fingers. The circles on the fingers serve not only to achieve an ideal composition of the hand and fingers but also to indicate the placement of finger rigging during the animation process. Rigging is the process of adding a skeletal structure to the 3D model, which functions as the pivot point for the object during animation. Each triangle and circle in the image represent a different rigging element. Rigging is applied to each body part individually—for example, the arm and fingers each have their own rigging structures. The small circles within the triangles function as joints or hinges, while the triangles act as the bones that pivot around these joints.

3. Development

The development stage is carried out after completing the design phase, which involves developing the Augmented Reality-based Sign Language learning media into a product that will subsequently undergo validation testing and revisions based on the results.

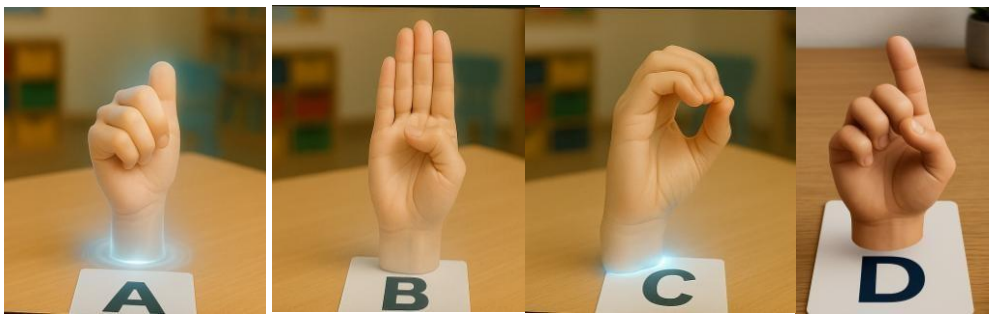

Figure 2. The Result of the Development of Augmented Reality Media for Sign Language

Figure 2. This figure shows the result of developing an Augmented Reality (AR) learning media for Sign Language, which applies the VISUALS principle to ensure the application serves its purpose as a visual instructor. This enables both deaf students and hearing individuals to use the application for learning SIBI (Indonesian Sign Language System). The values embedded in the VISUALS principle include: (a) Visible: the developed AR learning media is easy to see; (b) Interesting: the learning application utilizes augmented reality technology with 3D objects that act as sign language code instructors; (c) Simple: the AR learning media can be accessed anytime and anywhere; (d) Useful: the AR learning media helps users understand the basic codes of SIBI; (e) Accurate: the AR learning media is created and developed based on the SIBI Dictionary; (f) Legitimate: the AR learning media is developed using 3D objects that replicate the original gestures from the SIBI dictionary; and (g) Structured: the AR learning media is designed in accordance with the learning materials.

Table 1. Validation Test Results by Media Expert

Validator	AR Functionality					Application Performance					Device Compatibility						Total	Percentage
	Test item					Test item					Test item							
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	6		
Validator 1	5	4	4	5	4	5	5	4	4	4	5	4	4	5	5	4	72	90,00 %
Validator 2	4	4	5	5	4	4	5	4	5	4	4	5	5	4	5	4	71	88,75 %
Average																	**71,5**	**89,37 %**
Category																	**Strongly Agree**	

Table 2. Validation Test Results by Material Expert

Validator	AR accuracy and suitability			User interaction			Usability				Real-world environment testing					Total	Percentage
	Test item			Test item			Test item				Test item						
	1	2	3	1	2	3	1	2	3	4	1	2	3	4	5		
Validator 1	4	4	5	5	4	4	5	5	4	4	4	5	5	4	4	66	88,00 %
Validator 2	4	5	4	4	4	4	5	4	4	4	4	5	4	4	5	64	85,33 %
Average																**65**	**86,66 %**
Category																**Strongly Agree**	

Tables 1 and 2 present the validation test results of the Augmented Reality (AR) application, which involved various aspects such as functional testing, device compatibility testing, performance testing, accuracy and AR suitability testing, interaction testing, usability testing, and real-world environment testing. Each testing aspect has different objectives and methods, but all aim to ensure the application's quality and reliability, as well as to guarantee that the mobile application functions properly, meets user needs, is secure, responsive, and provides a satisfying user experience. Furthermore, the application is not only designed for deaf students but is also accessible for anyone who wishes to learn SIBI (Indonesian Sign Language System). The testing results demonstrated high percentage scores. The validation conducted by themedia expert validator reached an average percentage of 89.37%, while the validation by the material

expert validator reached an average of 86.66%. These average scores indicate that the application functions effectively, aligns with user needs, is safe, responsive, and delivers a satisfying experience.

4. Implementation

After developing the Augmented Reality (AR) Sign Language learning media, the next step is to implement the product. The resulting product is an AR-based Sign Language application designed to improve the learning outcomes of deaf students. Field trials were conducted after the validation tests by the experts. The field trials aimed to gather student responses to the developed product. In this implementation stage, 11 deaf students from the Special Education program at Universitas PGRI Argopuro Jember participated, with support from the lecturer in charge of the Sign Language learning course and facilitators throughout the learning process.

5. Evaluation

After conducting observations during the implementation stage and distributing questionnaires to the respondents, feedback was collected from a total of 11 participants. The respondents' answers served as the benchmark for this research. Their opinions were gathered through a set of questions provided in a questionnaire designed to measure the research variables, using a Likert scale. The data collected from the questionnaires distributed to the 11 respondents, who served as the research sample, are presented as follows:

Table 3. Respondents' Response Score Tabulation

No	Question	Score of Each Answer					Total respondents	Total score	Percentage
		5 (SA)	4 (A)	3 (N)	2 (D)	1 (SD)			
	User Effectiveness Variable								
1	Is this AR application easy to use?	9	2	0	0	0	11	53	96,36%
2	Does using Augmented Reality make it easier for me to understand the Sign Language learning material?	6	5	0	0	0	11	50	90,90%
3	Does the function of the Augmented Reality media help students learn sign language anytime and anywhere?	7	4	0	0	0	11	51	92,72%
	Information Effectiveness Variable								
4	Is the information on the sign language learning material displayed accurately and appropriately when using Augmented Reality?	10	1	0	0	0	11	54	98,18%
				Average				**52**	**94,54%**
				Category				**Highly Feasible**	

Note;

Strongly Agree	(SA)	=	score 5
Agree	(A)	=	score 4
Neutral	(N)	=	score 3
Disagree	(D)	=	score 2
Strongly Disagree	(SD)	=	score 1

Table 3 shows that the results of the questionnaire data collected from respondents on the use of Augmented Reality media in Sign Language learning at the Special Education Program of Universitas PGRI Argopuro Jember are categorized as “highly feasible”, with a respondent score of 94.54%. This result was obtained through Likert scale testing by distributing questionnaires as indicators to measure the effectiveness of using the Augmented Reality application media among deaf students.

The results of this study demonstrate that the Augmented Reality (AR)-based learning media for Sign Language education is highly feasible and effective for deaf students in the Special Education Program at Universitas PGRI Argopuro Jember. The media development followed the systematic stages of the ADDIE

model: Analysis, Design, Development, Implementation, and Evaluation. This process enabled the creation of a structured and responsive learning media that addresses the needs of deaf students, who have so far received limited support from interactive technology-based media in the process of learning Sign Language.

In the analysis stage, it was found that there was still a heavy reliance on conventional teaching methode and a lack of innovative media utilization by lecturers. This finding reflects a broader gap in education, as reported by (Garzón & Acevedo 2019) in their systematic review in Computers & Education, which states that despite the great potential of AR, its adoption in educational settings still faces several barriers, including the lack of knowledge and training for educators. For deaf students who process information visually, the lack of appropriate media can hinder understanding. This is where AR offers a highly suitable solution.

Additionally, interviews with deaf students revealed a clear need for interactive, visually based learning media. This aligns with research by (Cavus et al., 2021), which found that students with developmental disabilities (including those with hearing impairments) showed significant improvement in vocabulary comprehension when using AR-based videos compared to traditional picture card methods. This evidence reinforces that interactive 3D visualization, such as that developed in this study, can effectively bridge the understanding gap.

In the design process, the application was developed with careful attention to the details of hand and finger movements, which are the main components of Sign Language. The 3D models were designed using rigging techniques to ensure that every finger and hand movement closely resembles the actual gestures in the SIBI dictionary. (Hamdani et al., 2023) also emphasized that the accuracy of 3D object designs in AR-based learning media is crucial to ensure that sign gestures are correctly conveyed to users. The resulting prototype features realistic animation structures that help students visually comprehend the forms of the signs.

The development stage produced a Sign Language AR application that meets the VISUALS principles: Visible, Interesting, Simple, Useful, Accurate, Legitimate, and Structured. These principles ensure that the application is easy to use, engaging, informative, and accurate in presenting Sign Language movements based on official references from the SIBI Dictionary. Validation by media and content experts showed high percentages of 89.37% and 86.66%, categorized as "strongly agree." According to (Inkasari et al., 2024), expert validation serves as a quality filter to ensure that educational interventions are not only content-accurate but also functional and pedagogically sound before being tested on students. The high scores obtained indicate that this application meets both criteria excellently.

During the implementation stage, the application was tested on 11 deaf students. The trial results showed very positive responses, with an average user effectiveness score of 94.54%, based on questionnaire results. Students reported that the application is easy to use, provides accurate information, and helps them understand and practice Sign Language anytime and anywhere. These findings align with research by (Lestari et al., 2024), which stated that the use of AR in learning can increase the learning motivation of deaf students and make the learning process more flexible and enjoyable.

In the evaluation stage, data collected through Likert-scale questionnaires indicated that the majority of students strongly agreed with the benefits of this application. The high effectiveness score demonstrates that the application meets the learning needs for Sign Language both for self-study and classroom learning. Research by (Yaum et al., 2022) emphasized that even the most advanced learning media will fail if users find it difficult to operate. Thus, the positive responses from deaf students indicate not only the application's effectiveness but also that it was well-designed from a user experience perspective, making it a truly empowering tool.

Overall, this research confirms that developing AR-based learning media for Sign Language education significantly contributes to the field of special education. Beyond enhancing Sign Language comprehension, this application provides an inclusive learning experience that empowers deaf students to learn independently. With its high validation results, the application is expected to serve as an effective alternative learning medium in higher education, particularly in supporting the implementation of inclusive, technology-based education.

CONCLUSION

Based on the results of this study, it can be concluded that the Augmented Reality (AR)-based Sign Language learning media developed through the ADDIE model is proven to be effective, feasible, and aligned with the needs of deaf students in the Special Education Program at Universitas PGRI Argopuro Jember. The validation results showed scores of 89.37% from media experts and 86.66% from content experts, indicating that the application meets key aspects such as functionality, content accuracy, user interaction, and device compatibility. Additionally, the trial conducted with deaf students resulted in an effectiveness percentage of 94.54%, demonstrating that the application significantly helps students understand and practice Sign Language independently, anytime and anywhere. This application also fulfills the VISUALS principles: Visible, Interesting, Simple, Useful, Accurate, Legitimate, and Structured, thus providing a more interactive, enjoyable, and accessible learning experience for both deaf students and the general public interested in learning SIBI (Indonesian Sign Language System). Therefore, the development of this AR-based media can serve as an innovative solution to improve the quality of inclusive education in higher education institutions.

Based on the findings, several recommendations can be made for further development. First, it is recommended that Special Education programs in universities begin integrating technology-based learning media, such as AR, into the Sign Language curriculum. This integration can strengthen students' competence in communicating using Sign Language effectively and enjoyably. It is also important for lecturers teaching Sign Language courses to receive training or workshops on the utilization of AR media, ensuring that the learning process is optimized with the appropriate technological support. Second, the application is not only beneficial for deaf students but also holds great potential for use by the general public, educators, and healthcare professionals who wish to learn Sign Language. Therefore, efforts should be made to promote and disseminate this application so that more people can benefit from it. Lastly, for sustainable development, further research is recommended to measure the long-term effectiveness of the application and its impact on improving the communication skills of deaf students in various learning contexts and social situations.

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