International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Ingénierie des Systèmes d'Information
Vol. 30, No. 1, January, 2025, pp. 267-278
Journal homepage: http://iieta.org/journals/isi

Design of DSLIs Based on Virtual Reality for Deaf Students

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https://doi.org/10.18280/isi.300123

Received: 19 September 2024
Revised: 23 November 2024
Accepted: 18 December 2024
Available online: 25 January 2025

Keywords:
deaf students, sign language interpreter, Virtual Reality, technology, digital sign

ABSTRACT

This study aims to design a Digital Sign Language Interpreter (DSLI) based on Virtual Reality to assist deaf students in comprehending lecture material. The research employs a Research and Development (R&D) approach, encompassing four stages: (1) preliminary study, (2) data analysis, (3) product development, and (4) product validation. The development utilizes the Media Development Life Cycle (MDLC) method, consisting of five stages: concept, design, material collection, assembly, and testing. The results indicate that the DSLI application is highly feasible for extensive use by deaf students in lectures, based on evaluations from experts and users. This application represents a promising tool to enable deaf students to access lecture materials without a sign language interpreter's presence. However, the current version is limited to prerecorded sign language content prepared by interpreters, as it does not support real-time translation of lectures. While the DSLI demonstrates significant potential, further improvements are necessary to enhance its real-time functionality and broaden its practical application in classrooms. This study contributes to developing innovative solutions for inclusive education, providing an alternative for deaf students to engage in academic settings more independently.

1. INTRODUCTION

The Ministry of Education, Culture, Research, and Technology in 2020 stated that out of 4,621 higher education institutions, there are currently 1,588 students with special needs in 148 universities, of which 556 students are deaf [1]. Quality higher education has the challenge of providing accessible education services for deaf students [2]. Sign language is the primary means of communication for people who are deaf or hard of hearing. Much information is inaccessible to people who are deaf or hard of hearing due to the lack of Sign Language interpreters [3]. The presence of sign language interpreters helps bridge the communication gap between non-deaf peers in the classroom [4]. Deaf students cannot interact with others without sign language interpreters [5]. Sign language interpreters reduce the isolation of people who are deaf or hard of hearing in society on campus and help support deaf individuals in understanding lecture material in class [6]. Understanding the material of a course is necessary for the success of deaf students in lectures. This is to help understand complex lecture material that is exact and uses difficult words for deaf students. The presence of a sign language interpreter will make it easier for students to ask questions and give opinions and presentations during lecture sessions [4], and make it easier for students to get information about lecture materials. The primary role of a sign language interpreter is to mediate interactive dialogue between deaf students and their lecturers and classmates [7]. Sign language interpreters are a much-needed accommodation for deaf students, but the number of sign language interpreters is minimal [8, 9]. Data on sign language interpreters obtained by The Center of Indonesia Sign Language (PUSBISINDO) for 2018-2022 totaled 92 people throughout Indonesia [3].

The limited number of sign language interpreters cannot serve deaf students daily in university lectures. One innovation is using assistive technology to facilitate the sign language needs of deaf students. Technology can make it easier for deaf students to understand the material and be more motivated in lectures [10]. Assistive technology influences the development of communication for people who are deaf or hard of hearing and helps them understand the material in lectures [11]. The popular assistive technology used to help with learning problems is Virtual Reality (VR). VR is widely used in various sectors, including the world of education [12]. VR applications can improve the educational process for children with disabilities and can be a valuable tool to support the education of these children [13].

VR has emerged as a promising technology for various applications, including industrial operations [14], research and education [15], healthcare innovation [16], construction safety training [17], and industrial design education [18]. VR offers immersive experiences that can enhance learning, improve safety awareness, and facilitate needs identification in different fields. The technology has evolved significantly since its inception in the 1960s, with recent advancements making it more accessible and cost-effective [19]. VR applications in tourism and hospitality have shown positive outcomes, encouraging industry practitioners to incorporate this technology into their strategic plans [20]. Despite its potential, challenges remain in implementing VR, including organizational issues, technology maturity, and ethical considerations [14, 21]. As VR continues to develop, it is expected to have a disruptive impact on scientific fields and human communication.

An important aspect of VR in education is that VR content will allow students to recognize and explore abstract knowledge to be observed in a risk-free environment [22]. Universities engaged in education can utilize VR as a technology to improve the understanding of lecturers' speech in class when there are no sign language interpreters on duty to accompany them [2]. VR applications are innovative and efficient compared to conventional lecture materials delivery methods [23]. VR can be recommended to help understand the material and communicate in lectures [24]. VR is a tool for visualizing natural objects into virtual ones in a 3D form that can facilitate and construct the surrounding conditions into a virtual environment [25]. The virtual learning environment provides a new learning method for students to understand the material given by lecturers with DSLI features. This is possible with VR. The results of a 2023 study conducted through Focus Group Discussions (FGD) with Google Forms showed that 80% or 160 out of 200 deaf students at 28 campuses needed sign language interpreters to facilitate the lecture process. The findings regarding the need for VR showed that, on average, they agreed to use VR in lectures. The results of the study show that VR, which can be integrated, can display sign language for deaf students, which will make it easier for lecturers to explain lecture material.

Previous research has proven that VR is widely used for learning media, practicums, and training. VR can be used as a technology to assess the level of hearing of the deaf [26]. People who are deaf or hard of hearing use VR applications to train themselves to recognize the sounds of musical instruments; with VR, deaf individuals understand the intonation of the vibrations of the sound produced by musical instruments [27]. The use of VR for accessibility for the deaf and other voice recognition is the development of Ear VR to help analyze sound and inform users about the direction of the sound [28]. The use of VR can also be realized in learning games that can attract the attention of deaf individuals in understanding learning materials such as science, social studies, and mathematics [29]. VR helps people who are deaf or hard of hearing learn mathematics with sign language by translating abstract mathematical material [30]. Ghoul and Othman's research uses VR for sign language training for teachers and parents in America, where VR displays 3D avatars acting as tutors providing sign language basics [31].

The novelty of this research from previous research is that there has been no use of VR to help deaf students get Digital Sign language services through VR. Previous researchers researched the use of VR for self-compassion therapy in students with learning disabilities in 2022 [31], a sign language application for education was also developed [32]. This is an initial step to understanding the potential of combining VR and sign language conversion applications that can be used to help meet the lack of sign language interpreters for deaf students so that it can be realized digitally through the VR system.

Based on the problems described in this study, VR is currently used as a learning medium to introduce learning materials that have not been utilized for assistive technology for people who are deaf or hard of hearing in understanding sign language. Therefore, this study aims to design Digital Sign Language Interpreters (DSLIs) Based on Virtual Reality to help deaf students understand the lecture materials given by lecturers in class.

2. LITERATURE REVIEW

2.1 Virtual Reality (VR) as an assistive tool for deaf students in higher education

VR has emerged as a transformative educational tool for enhancing inclusive learning environments for deaf students in higher education. The role of VR in supporting these students is multifaceted, offering unique opportunities to bridge communication gaps and foster engagement through immersive experiences. VR can simulate real-world scenarios that are often inaccessible to deaf learners, thereby providing them with experiential learning opportunities that enhance comprehension and retention of complex concepts [33, 34]. This immersive technology allows for the visualization of abstract ideas, which is crucial in subjects that rely heavily on auditory information, thus enabling deaf students to engage with content in a more meaningful way [35, 36].

Previous studies have demonstrated the effectiveness of VR in improving educational accessibility and engagement for students with disabilities, including those who are deaf. For instance, research indicates that VR can significantly enhance learning outcomes by providing interactive and visually rich environments that cater to diverse learning styles [37, 38]. VR has shown significant potential in enhancing educational accessibility and engagement for students with disabilities. Studies indicate that VR improves learning outcomes, particularly in subjects requiring spatial understanding, with test scores increasing by 15-30% [39]. VR has been found to increase student motivation and interest [40, 41], with constructivism and experiential learning being the most appropriate approaches for VR-based education [42]. Research demonstrates that VR promotes greater student learning compared to traditional methods, especially when using immersive systems [43]. For students with intellectual and developmental disabilities, VR exergaming has increased the duration and intensity of physical activity [44]. However, challenges remain regarding accessibility, inclusivity, and teacher training, necessitating further research and development in this field.

In particular, VR applications have been shown to increase motivation and participation among students, as they can interact with content in ways that traditional educational methods do not allow [13, 45]. Furthermore, VR has been utilized to create tailored educational experiences, such as sign language MOOCs, which specifically address the learning needs of deaf students [46, 47]. These studies highlight VR's potential to facilitate learning and empower students by giving them agency in their educational journeys. The synthesis of these findings underscores the transformative potential of VR as an assistive tool for deaf students in higher education. By leveraging the immersive capabilities of VR, educators can create inclusive learning environments that accommodate the unique needs of deaf learners. As VR technology continues to evolve, its integration into higher education curricula can pave the way for more equitable learning experiences, ultimately contributing to the academic success of deaf students [48, 49].

In conclusion, the literature reveals a promising landscape for the application of VR in supporting deaf students in higher education. By facilitating immersive and interactive learning experiences, VR has the potential to enhance educational accessibility and engagement significantly. As institutions increasingly adopt this technology, it is crucial to continue exploring its applications and effectiveness in creating inclusive educational environments that cater to the diverse needs of all learners.

2.2 Challenges and research gaps in developing VR-based DSLIs

The development of VR technology for sign language interpretation presents several challenges that must be addressed to enhance its effectiveness and usability. One significant challenge is the limitation in real-time translation capabilities. Current VR systems often struggle to provide instantaneous interpretation of sign language due to the complexities involved in accurately capturing and translating the nuanced movements and expressions inherent in sign languages [50, 51].

Recent research highlights advancements and challenges in developing VR technology for sign language interpretation. While VR environments show promise for sign language learning and communication [52, 53], technological limitations still affect the quality of these experiences. Real-time translation remains a challenge, with mobile platforms offering potential solutions [54, 55]. Movement accuracy is crucial, with studies exploring various techniques like MediaPipe and hybrid CNN+Bi-LSTM models for improved recognition [56]. Gesture recognition in VR using devices like Leap Motion has shown promising results [57, 58]. However, challenges persist in achieving high accuracy and visual quality in sign language recognition, translation, and video generation. Despite these obstacles, technological advancements in image processing and deep learning continue to drive improvements in sign language-related tasks.

Among these challenges, system latency is a key factor impacting the practicality of VR-based sign language translation systems. One of the critical challenges in VR-based sign language translation systems is system latency, which refers to the delay between input (gesture recognition) and output (avatar rendering). High latency significantly reduces the effectiveness of real-time translation, causing delays in communication that may frustrate users and hinder their understanding of lecture material. Latency issues arise from several factors, including gesture capture accuracy, the processing speed of recognition algorithms, and the rendering time of 3D avatars in the VR environment. Previous studies highlight that achieving latency below 50 milliseconds is essential for seamless real-time interaction, yet many existing systems struggle to meet this benchmark due to hardware and software limitations [58]. Addressing system latency is crucial to ensuring the feasibility and effectiveness of VR sign language interpreters in educational settings.

Another critical aspect of VR usability is managing physiological issues like dizziness and visual fatigue. These challenges arise from motion sickness caused by discrepancies between visual stimuli and physical motion, as well as eye strain from prolonged focus on 3D graphics [59]. For deaf students, such discomfort could disrupt concentration and learning. Mitigation strategies include limiting usage duration, ergonomic interface design, and regular breaks, while future improvements in frame rates and latency could further reduce these effects.

Additionally, the accuracy of movement representation is crucial; VR avatars must replicate the intricate hand shapes, movements, and facial expressions that are vital for conveying meaning in sign language [59, 60]. The need for high fidelity in motion tracking and gesture recognition is paramount, as any discrepancies can lead to misinterpretation and hinder effective communication [61, 62]. Furthermore, the integration of contextual understanding in VR systems remains underdeveloped, which is essential for interpreting the subtleties of sign language in various communicative contexts [63, 64]. In addition to these challenges, there are notable gaps in the current literature regarding the application of VR avatar-based solutions for sign language interpretation, particularly in higher education settings [55]. While some studies have explored the potential of VR in language learning and interpretation, there is a lack of comprehensive research focusing specifically on the effectiveness of VR avatars in facilitating sign language interpretation for educational purposes.

Most existing research tends to concentrate on technical aspects of sign language recognition and the development of algorithms for gesture detection rather than on the pedagogical implications and user experiences of VR-based sign language interpreters in educational contexts [65, 66]. This gap indicates a need for further exploration of how VR can be effectively integrated into educational frameworks to support deaf students and enhance their learning experiences [67, 68]. Moreover, the potential for VR to create immersive environments that simulate real-life interactions and provide practice opportunities for interpreting skills remains largely unexplored. In conclusion, while integrating VR technology into sign language interpretation holds significant promise, it is accompanied by considerable challenges and research gaps. The limitations in real-time translation and movement accuracy must be addressed to improve the reliability of VR-based interpreters. Additionally, the current literature lacks a focused examination of VR avatar-based solutions in higher education, highlighting the need for further research to explore their effectiveness and applicability in educational settings. Addressing these challenges and gaps will be crucial for developing robust VR systems that facilitate effective communication and learning for deaf students, ultimately contributing to a more inclusive educational environment.

3. METHODS

3.1 Research design

This research aims to develop DSLIs Based on Virtual Reality to help deaf students understand the lecture material given by lecturers in class. Based on the research objectives, the type of research used is development research or Research and Development (R & D). Development research is a product development model from design, validation, testing, and widespread product dissemination [69]. Development research is used to develop DSLIs in Virtual Reality.

The research procedure carried out is educational research and development. Educational research and development are a process of developing a product in the world of education, which goes through product validation tests involving program evaluation and development, resulting in a product in the world of Education in the form of DSLIs Based Virtual Reality media to help deaf students understand the lecture material given by lecturers in class. The research procedure carried out in this study generally refers to the development research design [69], which consists of 10 stages, namely: (1) research and data collection; (2) planning; (3) product draft development; (4) initial product testing; (5) initial product revision; (6) final product trial; (7) final product revision; (8) final product testing; (9) final product revision; and (10) dissemination and implementation.

In this study, an adaptation was carried out with the model developed by Isnaeni [70] with development stages, namely (1) preliminary study stage, (2) data analysis stage, (3) product development stage, and (4) product validation stage. The research and development steps can be clearly illustrated in Figure 1.

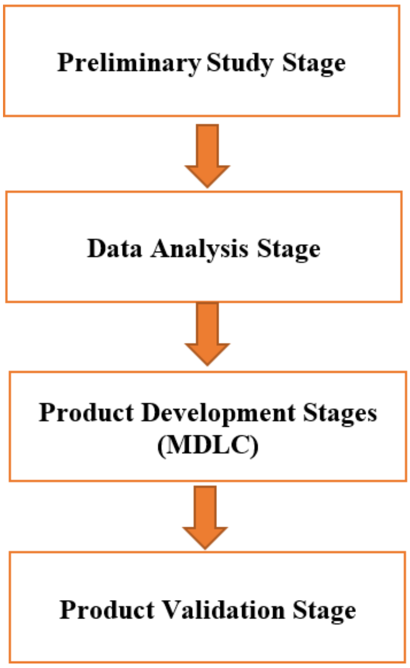

Figure 1. Research design

3.2 Research subject and population

This stage focuses on inclusive campuses in Indonesia that serve deaf students as the research area. This research was conducted involving 200 deaf students from 28 inclusive campuses, selected using a purposive sampling method [71]. These campuses were chosen to provide a representative overview of diverse educational contexts and to gather insights into the specific needs of deaf students in lectures. Respondents were undergraduate students aged 18–25 from various disciplines such as education, engineering, and social sciences. They were selected based on their experience of attending lectures without a sign language interpreter.

The research location and respondent selection aimed to identify challenges and potential solutions that could inform the development of the DSLIs Based Virtual Reality application. This process ensures the product development aligns with the practical needs and expectations of deaf students, providing insights into the application's limitations and its suitability for inclusive education contexts.

3.3 Data collection tool

There are various activities that researchers will carry out at this stage, including (1) observation, which is done by observing the problems of deaf students in lectures. (2) Focus Group Discussion (FGD), carried out by gathering deaf students to provide relevant information about the applications needed to facilitate lectures and provide suggestions in developing products that researchers are developing. (3) A literature study was carried out to collect information and strengthen the theoretical basis through journals and proceedings indexed by Scopus and WoS in developing products developed in research Yin [71] and Thalheimer and Cook [72].

From the series of activities, evaluation dimensions and criteria have been established to assess the system's effectiveness comprehensively. The evaluation focused on four dimensions: translation accuracy, system latency, ease of use, and user satisfaction. These dimensions are operationalized through specific indicators, as described in Table 1. The integration of these dimensions ensures that the evaluation aligns with the technical performance of the system as well as the practical needs of deaf students in the context of inclusive education.

Table 1. Evaluation indicators and criteria for VR system

Assessment Aspect	Indicator	Number of Items
Practicality Aspect	- Ease of use of the application in supporting the needs of deaf students. - Effectiveness of the application in providing sign language interpreter services.	2
Display Aspect	- Quality of the user interface. - Visual clarity of the sign language avatar.	2
Programming Aspect	- Stability of the application system during use. - The application is responsive to user input.	2
Ease of Use Aspect	- Ease of navigation of the application interface. - Simplicity of features that support user accessibility.	2

*Note: Adapted from the study by Novaliendry et al. [73]

3.4 Application development methodology

In developing DSLIs products based on Virtual Reality using the MDLC (Media Development Life Cycle) method, there are five stages: concept, design, material collection, assembly, and testing. The details of each stage will include:

Concept: The first stage includes Focus Group Discussion (FGD) activities with key stakeholders, including deaf students, sign language expert lecturers, and IT professionals, to identify the need to create the application. This process is carried out to ensure that all critical information is collected successfully. Careful consideration is given to selecting suitable elements for the application, such as visuals, animations, color schemes, audio features, and textual content. Subsequent steps include planning the integration of course materials into Sign Language, designing the user interface, defining the application's dimensions, and mapping out navigation pathways to deliver an optimal and seamless user experience for the DSLIs in a Virtual Reality environment.

Design: At this stage, a standard design is needed to describe, design, and document the model or display of DSLIs Based Virtual Reality.

Material Collection: At this stage, material collection is carried out during the development of application design, including collecting text, images, video recordings of sign language, and audio. The aim of gathering materials is to guarantee that suitable and relevant content is available for developing the application. Materials are meticulously chosen according to the specific needs and goals of the application and designed to align with the courses necessary for deaf students.

Assembly: Involves organizing and incorporating the collected materials into a Virtual Reality application that utilizes DSLIs, ensuring it is accessible and user-friendly for deaf students.

Testing: The testing phase follows the assembly process, where the application is run. The researcher performs two validation tests during this phase: expert and user. These tests evaluate the application's practicality, design, programming, and user-friendliness. The assessment categories can be seen in Table 2.

Table 2. Product assessment standards

No.	Average Value	Category
1	80 – 100	Very Eligible
2	60 – 79	Eligible
3	40 – 59	Quite Eligible
4	0 – 39	Not Eligible

*Note: Adapted from the study by Suartama and Salehudin [74]

4. RESULT

As stated in the previous section, this study aims to develop DSLIs Based on Virtual Reality to help deaf students understand the lecture material given by lecturers in class. By adopting the MDLC framework and incorporating evaluations from experts in Information Technology, Learning Media, and Special Education, as well as feedback from deaf students, the application aims to deliver an optimised and impactful learning tool. This tool is designed to assist deaf students in comprehending lecture materials using a Virtual Reality system integrated with Sign Language features.

4.1 Concept

At the concept stage, the researcher determines the substance contained in DSLIs Based Virtual Reality. The users of this application are deaf students from the Special Education Undergraduate Program. The duration of use of this application is adjusted to the lecture hours taken by deaf students, where there are no sign language interpreters who can assist the lecture process during those hours. This application accommodates various media formats, such as images and files. To boost interactivity, it incorporates navigation buttons that allow users to zoom and choose sign language avatars, enhancing the clarity of signs related to the lecture content delivered by the instructor. The DSLIs Based Virtual Reality system is compatible with mid-range VR headsets like Oculus Quest 2, motion tracking devices like Leap Motion, and computers with at least an Intel i5 processor, 8 GB RAM, and a mid-tier GPU. These requirements ensure accessibility and functionality, making the system feasible for universities with varying resource levels.

The description of the DSLIs Based Virtual Reality concept can be seen in Table 3 below.

Table 3. Concept description

Assistive Technology Name	DSLI-VR
Subject	Deaf college student
Dosage for use	According to class hours
Picture	.jpg
Animasi	.fbx
Sound	.mp3
Menu	Navigation buttons (Start, back, course selection, avatar selection (full-body at au half body)
Refresh Rate	90 Hz (ensures smooth rendering and minimizes motion blur for better user comfort)
Visual Resolution	1920x1080 pixels (provides clear and detailed sign language animations for enhanced comprehension)
System Stability	Stable operation for up to 2 hours (tested under continuous usage conditions, ensuring reliability in classroom settings)

*Note: Adapted from the study by Novaliendry et al. [73]

4.2 Design

The design process of the DSLI Virtual Reality application was carefully aligned with the findings from the literature study and the needs analysis conducted during the Focus Group Discussion (FGD) with deaf students.

This comprehensive approach ensured that the system addressed specific challenges faced by deaf students in understanding lecture materials without the presence of a physical sign language interpreter. The application allows deaf students to access a virtual environment using VR technology, where they can select, courses deemed challenging to comprehend. Within this virtual space, students can choose between two types of sign language interpreter avatars: a full-body avatar for a more immersive experience or a half-body avatar for simplicity and focus.

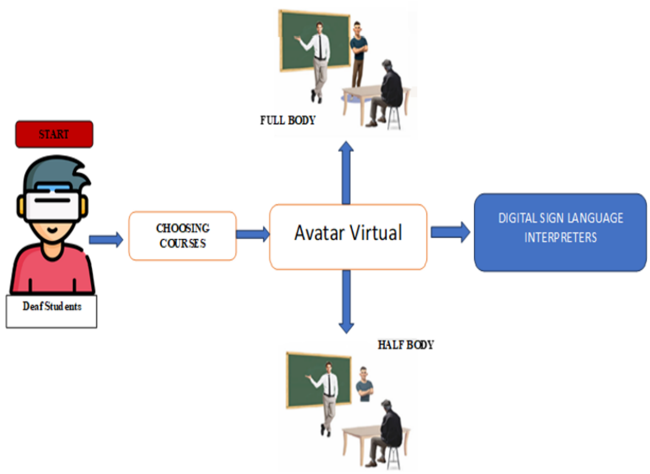

Figure 2. Flow map of a running system

Once the selections are made based on the student's preferences, the application delivers real-time translations of the lecture material, helping them follow the content more effectively.

This design not only enhances accessibility but also empowers deaf students by providing a flexible and adaptive learning environment. The process ensures the system meets their needs, bridging communication gaps in inclusive education settings. An overview of the system that will run can be seen in Figure 2.

4.3 Material collecting

Several elements with different descriptions and formats must be prepared to compile DSLIs Based Virtual Reality when collecting materials. The elements needed in this application because it is VR-based are text, images, and videos. The initial component consists of textual content, which details the application's purpose, usage instructions, name, version, and menu options. The next component encompasses a variety of visual materials, such as alphabetic letters (A–Z), numerical figures based on Targets/Competencies, avatars representing sign language, menu symbols, and the application's logo. These visuals are preserved in .fbx (file format for 3D animation) object file formats to ensure compatibility with 3D environments. The third element is storing this video in .mp3 or mp4 format. The video element captures the movements of the sign language interpreter recorded when explaining the lecture material the lecturer in class will deliver. This recording will be used as a movement on the avatar used in the DSLIs Based Virtual Reality application so that the avatar movements in the virtual environment seen by students look real and easy to understand. By combining these various elements and formats, the product, a DSLI-Based Virtual Reality Application, aims to provide a comprehensive understanding of the material for its users. The materials needed to make the DSLIs Based Virtual Reality application can be seen in detail in Table 4.

Table 4. Multimedia components on the product

No.	Element	Description	Format
1	Text	Details include an explanation of the application, its intended use, the application name, version, and the structure of the application menu	.txt
2	Image	• Alphabetic letters A to Z • Format numbers 0 to 9 • Information about competencies for students in course • Sign language Avatar (Full body or HALF BODY) • Menu icon • Application logo and University logo	.fbx
3	Video	Sign language interpreter movements recorded while explaining course material to be delivered by the lecturer in class	.mp3 or .mp4

4.4 Assembly

The product development process uses several software, namely motion capture, which captures movements using OptiTrack (Body), StretchSense (Hands), and FACEWARE (Face). The application captures movements similar to accurate sign language interpreters so that deaf students can feel the experience of understanding the material virtually with movements identical to sign language interpreters in the real world. The following software to create movements captured from motion capture can be included in avatars using Autodesk Motion Builder and Autodesk Maya. The application will display symbols, images, and easy-to-understand avatars that describe sign language movements for deaf students processed in Unity, then use Google VR box so that students can understand the lecture material with sign language interpreter avatars in a virtual environment.

Meanwhile, the DSLIs Based Virtual Reality system was developed using open-source software platforms and widely available VR hardware to ensure accessibility and cost-efficiency. This approach minimizes financial barriers, allowing other institutions to adopt and replicate the system with minimal investment. Open-source tools also simplify updates and maintenance, enhancing the system's feasibility for widespread use in universities while promoting inclusivity in education.

Building on this foundation of accessibility and adaptability. The DSLIs Based Virtual Reality system supports Indonesian Sign Language (BISINDO) with a database of 500 academic signs and a modular design to accommodate regional variations. While the system offers offline functionality for accessing preloaded sign language content, an internet connection is required to activate and animate the sign language interpreter avatar in real-time. This dual capability ensures that the system remains accessible in diverse teaching environments, with offline access supporting content review and internet connectivity enabling dynamic interaction during lectures.

The following in Figure 3 can be seen as the user interface of the DSLIs Based Virtual Reality application.

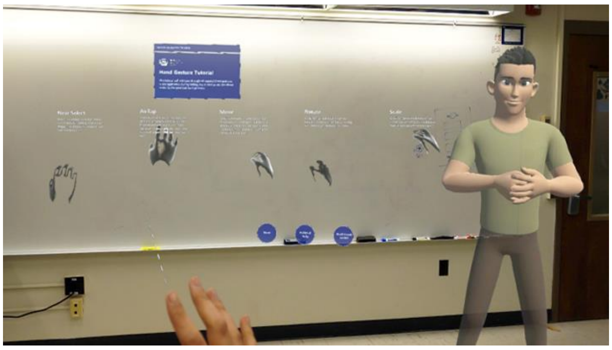

Figure 3. User interface in course

4.5 Testing

At this testing stage, the researcher involved experts in information technology, learning media, Special Education, and deaf students. This testing involved ten experts who were included to provide a feasibility assessment from the perspective of the feasibility of the application developed according to their field of expertise, thus strengthening the results of the application development that is suitable for use by deaf students.

The testing phase focused on validating the feasibility of the DSLIs Based Virtual Reality system from an expert perspective. Guided by pre-defined criteria, including practicality, display quality, programming stability, and ease of use, experts evaluated the system's technical parameters, such as latency and gesture recognition accuracy.

The testing also involved 30 deaf students, who are the direct users of this application, to evaluate its feasibility and ease of use in supporting their understanding of lecture materials. Additionally, experts in learning media, information technology, and special education participated to assess the system from a professional perspective. Using a structured instrument grid, these experts evaluated key aspects such as practicality, display quality, programming stability, and ease of use. Including users and experts ensured a comprehensive validation process, strengthening the system's feasibility and confirming its suitability in inclusive education settings. The test results from experts and users can be seen in detail in Table 5.

The test results show that the average value given by experts and users of the DSLIs-Based Virtual Reality application is feasible and worthy of being used massively for deaf students in lectures. In the next stage, researchers will make revisions to disseminate the DSLIs Based Virtual Reality application for deaf students who need help in lectures.

Table 5. Test results of DSLIs application based on Virtual Reality

No	Assessment Items	Average Value	Category
1	Practicality Aspect	80	Very Eligible
2	Display Aspect	85	Very Eligible
3	Programming Aspect	75	Eligible
4	Ease of Use Aspect	85	Very Eligible

5. DISCUSSION

Sign language is an essential communication tool for individuals with hearing impairments, enabling interaction with those who are not deaf. Despite technological advances such as mobile applications, desktop and web applications, and new teaching strategies implemented by lecturers, deaf students still face significant challenges in learning sign language [31]. In an inclusive campus environment, sign language interpreters play a vital role in facilitating student learning [75]. Virtual Reality (VR) technology's rapid advancement has created novel possibilities for enriching the real virtual environment experience for deaf individuals [52]. This technology has been proven effective in various applications supporting people with disabilities, including the deaf [76]. The VR-based sign language application designed and developed in this study significantly contributes to increasing communication accessibility for individuals with hearing impairments [29].

The experience of using VR provides a realistic experience in understanding virtual sign language interpreters and explaining complex lecture materials to deaf students [77]. The VR environment facilitates deep interaction and real-time feedback for deaf students, making lectures more interactive with sign language interpreter avatars that explain the material presented by the lecturer in class [78]. VR manifests assistive technology's role in helping deaf students during campus lectures. Recent research highlights the potential of multimedia and technology in enhancing special education and general learning outcomes. Interactive multimedia has shown promise in improving student engagement and understanding across various subjects, including mathematics, religious education, and digital logic [79-81]. E-learning platforms and audiovisual materials have been developed to support inquiry-based learning and character education [82, 83]. For special education, multimedia interventions have significantly improved preservice teachers' knowledge and skills for reading instruction [84]. Web-based and project-based learning approaches have also improved student mastery of multimedia creation [85]. These findings underscore the importance of integrating multimedia and technology in general and special education contexts. Previous research has demonstrated the significant role of VR-based sign language as a substitute for human interpreters, which is particularly beneficial for students who require explanations for complicated lecture materials that would otherwise be challenging to understand without sign language.

However, there are challenges in implementing VR technology in special education, particularly concerning infrastructure and technological readiness. The development of increasingly sophisticated technology allows VR to be used by real individuals to create virtual characters/avatars in real time, helping deaf students understand the material through sign language in both virtual and real-world settings [52]. Conversely, user adaptation to Virtual Reality (VR) technology in special education, particularly for students with hearing impairments, faces various challenges that must be addressed to ensure effectiveness. A primary challenge is the inadequate infrastructure and accessibility of technology, which frequently impedes the implementation of VR in special education classrooms [13]. Numerous educational institutions lack the necessary hardware and software to support immersive VR experiences, thus creating disparities in educational access for students with special needs [41]. Furthermore, insufficient training for educators in utilizing this technology may diminish the potential benefits of VR, as teachers may lack the requisite knowledge or skills to integrate VR into their curricula [86]. Consequently, it is imperative to develop comprehensive training programs and enhance technological infrastructure in schools to facilitate improved user adaptation to VR technology, thereby creating a more inclusive and effective learning environment for students with hearing impairments.

Implementing Virtual Reality (VR) technology in special education encounters several significant challenges, particularly for students with hearing impairments, primarily related to infrastructure and technology readiness. A foremost obstacle is the insufficient technological infrastructure in educational institutions, which can impede the effective deployment of VR systems. Numerous schools and universities may lack the requisite hardware, software, or internet bandwidth to support immersive VR experiences, resulting in disparities in access and quality of education for students with disabilities [17, 87]. Moreover, the integration of VR into existing curricula is often not anticipated by standard educational syllabi, necessitating a reevaluation of pedagogical approaches and the professional development of educators to utilize these technologies effectively [88]. Additionally, there are concerns regarding the cost of VR technologies, which can be prohibitive for many educational institutions, particularly those serving special education populations [32, 89]. Teacher training is another critical aspect; educators must be adequately prepared to implement VR tools in their teaching practices, which requires ongoing professional development and support [39, 80]. Lastly, data privacy and security issues, particularly when handling sensitive information related to students with disabilities, further complicate the adoption of VR technologies in special education settings. VR systems support modalities such as body posture, movement, finger, and facial expression, enabling high-fidelity sign language-based communication in real time [9, 31]. This adaptability is crucial for ensuring students and educators are prepared to integrate and utilize VR technology effectively. Addressing these challenges is essential for leveraging the full potential of VR in creating inclusive and effective learning environments for students with special needs.

Sign language avatars play a pivotal role in enhancing learning in the VR environment. Sign language interpreters are projected into virtual space and translated into text, movement, and audio, enabling long-distance and two-way communication between lecturers and deaf students [78] VR containing sign language in lectures can make learning more enjoyable and motivating in understanding lecture material [90]. The multimedia content development, such as text, images, and videos that support this VR-based system, plays an essential role in creating a more comprehensive and engaging learning environment.

However, it is essential to acknowledge the limitations of this study and its primary objective. This study is limited to validating the feasibility of the DSLIs Based Virtual Reality system from an expert perspective. The testing focused on key aspects such as practicality, display quality, programming stability, and ease of use, which were assessed through structured evaluation criteria. Comparative data on learning effectiveness and comprehension levels were not included, as the primary objective was to determine the system's readiness for educational use.

Integrating Virtual Reality (VR) technology with avatars for sign language interpretation offers significant benefits for inclusive education, particularly for deaf and hard-of-hearing students. By creating immersive and interactive environments, VR facilitates more effective communication and learning experiences tailored to these students' unique needs. The development of DSLIs in VR allows deaf students to overcome the limited availability of human sign language interpreters on campus, enabling them to access lecture materials without waiting for an interpreter. This technological advancement enhances the educational experiences of deaf students, ensuring they have equitable access to high-quality learning, thereby contributing to a more inclusive learning environment where all students, regardless of hearing ability, are provided with equal opportunities to succeed.

6. CONCLUSION

This study developed a DSLIs application based on Virtual Reality (VR) to help deaf students understand lecture materials. Using the MDLC model, the application was tested with experts in information technology, learning media, and special education, as well as with deaf students. The results indicate that the application is highly feasible regarding practicality, appearance, and ease of use. Deaf students reported being able to use the application quickly and easily, and they felt more confident in lectures because they could independently understand the material without needing a sign language interpreter present. These findings demonstrate that VR technology can effectively assist deaf students by providing DSLI avatars that create an immersive and interactive learning environment. This application shows strong potential for improving sign language education based on positive expert and user evaluations. It's considered highly feasible for widespread educational use, particularly for integrating sign language learning into lectures and promoting inclusive education for people who are hard of hearing. However, there is room for improvement, as the current version does not support the real-time translation of sign language lecturers deliver. Instead, it relies on pre-recorded sign language content input into the digital interpreter avatar.

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