

The Impact of AI-Based Sign Language Translation on Reading Instruction for Students with Hearing Impairment: A Theoretical Analytical Study

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ABSTRACT:

Artificial intelligence applications are undergoing rapid development in the field of special education, and AI-based sign language translation has emerged as one of the most promising technologies that can contribute to improving reading instruction for students with hearing impairments by enhancing access to educational content and facilitating the comprehension of written texts. This study aimed to analyse the role of intelligent sign language translation in the development of reading skills, review its educational applications, and highlight the potential for its integration with other AI technologies, such as adaptive learning, computer vision and large language models. The study adopted a qualitative approach through a theoretical-analytical study, based on an analysis of recent scientific literature using document analysis and qualitative content analysis. The results showed that AI-based sign language translation contributes to enhancing reading comprehension, developing vocabulary and improving interaction with texts; furthermore, its integration with other smart technologies supports the creation of more inclusive learning environments that are adapted to the needs of students with hearing impairments. The study also highlighted a number of challenges, most notably the diversity of sign languages, the lack of Arabic databases, and the need for more accurate models that take into account the linguistic and cultural characteristics of the deaf community. The study concludes that intelligent sign language translation represents a promising trend in the development of literacy education, and recommends the development of specialised educational applications and the conduct of pilot studies to verify the effectiveness of these technologies in various educational settings.

Keywords: AI-based sign language translation, Reading instruction, Hearing impairment, Artificial intelligence, Special education.

1. Introduction

The use of artificial intelligence in education is developing at a rapid pace, with its applications now representing one of the most prominent recent trends in the development of educational environments that support personalised and inclusive learning. Among these applications, AI-based sign language translation has emerged as a promising technology that helps improve access to educational content for students with hearing impairments, by converting text or speech into digital sign language, or converting sign language into written text using natural language processing, computer vision, deep learning and advanced linguistic models (Bragg et al., 2019; Camgoz et al., 2020)

This technology is of particular importance in reading instruction; as many students with hearing impairments face challenges in understanding written texts due to limited linguistic experience and the differences between written language and sign language, which may affect vocabulary development, reading comprehension and academic achievement (Marschark & Spencer, 2016). Despite significant advances in artificial intelligence applications, most studies have addressed sign language translation from a technical perspective focused on improving recognition and translation algorithms, whilst studies investigating its integrated use in reading instruction remain limited, particularly in the context of integrating it with adaptive learning techniques, linguistic models and computer vision.

In light of this gap, the research problem lies in the need to highlight the educational role of AI-based sign language translation in developing reading instruction for students with hearing impairments, and to elucidate the mechanisms by which it integrates with other smart technologies to create more inclusive and effective learning environments. This section therefore aims to analyse the concept of smart sign language translation, review its applications in reading instruction, and demonstrate its contribution to the development of vocabulary and reading

comprehension, whilst discussing the key challenges and future trends.

Recent literature emphasises that the integration of smart sign language translation technologies with artificial intelligence applications contributes to improving access to educational content, enhancing interaction, and supporting learner autonomy; it also represents one of the promising research trends in the field of special education and inclusive education (Bragg et al., 2019; Camgoz et al., 2020; Kasneci et al., 2023). With this in mind, this theme aims to present a theoretical analysis grounded in recent scientific literature, thereby helping to clarify the educational value of this technology in developing reading instruction for students with hearing impairments.

2. Methodology

2.1 Research Design:

This study adopted a qualitative research approach, utilising a theoretical analytical study, with the aim of analysing the scientific literature relating to the use of artificial intelligence-based sign language translation in teaching reading to students with hearing impairments, and to develop an analytical framework that clarifies the roles of this technology and its educational applications, as well as its relationship with other technologies such as adaptive learning, computer vision and large language models.

2.2 Research Tools:

Given the theoretical nature of the study, the primary research method was document analysis, alongside qualitative content analysis of relevant peer-reviewed studies and research. Data sources included articles published in scientific journals indexed in the Scopus and Web of Science databases, as well as academic books, conference papers, systematic reviews, and reports issued by international organisations specialising in artificial intelligence and special education.

2.3 Research Procedures

The study followed a set of methodological procedures to achieve its objectives, namely:

1. Defining the research topic and formulating its research questions and objectives in light of the challenges associated with teaching reading to students with hearing impairments.
2. Compiling recent scientific literature on artificial intelligence-based sign language translation, with a focus on studies published in recent years.
3. Classifying the studies according to key themes, including the concept of intelligent sign language translation, its educational applications, its impact on the development of reading skills, technical and pedagogical challenges, and future trends.
4. To conduct a critical and comparative analysis of the findings of previous studies to identify points of agreement and disagreement, and to pinpoint research gaps.
5. To draw conclusions and construct an analytical framework that clarifies the role of intelligent sign language translation in developing reading instruction for students with hearing impairments.

2.4 Data Analysis

The study relied on qualitative content analysis as the primary method for analysing the scientific literature, with the aim of identifying key concepts and trends relating to the applications of sign language translation in reading instruction. Comparative analysis was also used to compare the findings of previous studies and analyse the synergies between sign language translation techniques and other artificial intelligence-based techniques, with a view to presenting a comprehensive scientific perspective that helps to explain the potential of this technology and guide future applied research.

2.5 The Concept of Artificial Intelligence-Based Sign Language Translation

Artificial intelligence-based sign language translation refers to systems that use artificial intelligence technologies to convert language from one form to another, such as:

- Converting written text into digital sign language.
- Converting spoken speech into sign language.
- Converting a user's signs into written text.

These systems rely on the integration of several technical fields, the most important of which are:

1. Natural Language Processing (NLP) to understand sentences and meanings and analyse linguistic structure.
2. Computer Vision (Computer Vision) to recognise hand and body movements and facial expressions.
3. Deep Learning to train models to recognise motor and linguistic patterns.
4. Animation and virtual avatars to produce visible digital sign language.

2.6 The importance of sign language interpretation in teaching reading to students with hearing impairments

2.6.1 Linking written language to visual meaning

The transition from written text to meaning presents a challenge for some students with hearing impairments, particularly when their linguistic experience is limited.

Sign language interpretation helps to:

- Explain written words visually.
- clarifying abstract concepts.
- supporting the understanding of sentences and texts.
- linking the written word to movement and meaning.

When presenting a new word such as 'justice' or 'cooperation', the system can provide the appropriate sign alongside an image or a contextual example, helping the student to form a clearer concept.

2.6.2 Developing reading vocabulary

A limited vocabulary is one of the most significant challenges affecting reading among students with hearing impairments.

Artificial intelligence can support vocabulary development by:

- Translating new words into sign language.
- Displaying the sign alongside the written word.
- Repeating the exercise according to the student's level.
- Building a personalised dictionary of vocabulary tailored to the learner's needs.

This helps to develop the connection between the written word, the sign and the meaning.

2.6.3 Supporting reading comprehension of texts

Teaching reading is not limited to recognising words; it also requires an understanding of the text's overall meaning. This is where sign language interpretation can help by:

- Translating paragraphs into signs.
- Explaining the main ideas.
- Clarifying the relationships between events.
- providing visual summaries of texts.

The intelligent system can select the appropriate level of explanation according to the student's ability.

2.7 Applications of Artificial Intelligence in Sign Language Translation

2.7.1 Converting written text into digital sign language

(Text-to-Sign Translation)

This application is one of the most closely linked to reading instruction, as the system analyses the written text and converts it into signs displayed via:

- a 3D virtual avatar.
- educational videos.
- animations.

Practical example:

Text: "The pupil went to school."

The system analyses the sentence and then produces a sequence of digital signs that convey its meaning.

2.7.2 Speech-to-Sign Translation

Speech-to-text technology can be integrated with sign language translation, resulting in the following process:

Teacher's speech → Written text → Digital sign language

This allows the student to follow the oral explanation in the classroom more clearly.

2.7.3 Recognising sign language and converting it to text

(Sign-to-Text Translation)

Using computer vision, some systems can analyse:

- Hand movements.
- The direction of movement.
- Finger shapes.
- Facial expressions.

They then convert the sign language into written text.

This technology can help students express their ideas and improve their reading and writing skills.

2.8 Integrating sign language translation with adaptive learning

The combination of sign language, artificial intelligence and adaptive learning represents a cutting-edge approach to reading instruction, whereby the system is able to:

- Assess a pupil's reading level.
- Identify the words they find difficult.
- Select the appropriate sign.
- Adjust the way content is presented.
- Provide individualised remedial activities.

For example, if the system detects that a pupil is struggling to understand a set of vocabulary words, it provides additional practice using text, images and signs.

2.9 The role of large language models in sign language translation

The emergence of large language models has contributed to the development of translation systems, as they are capable of:

- Understanding the full context of a sentence.
- Analysing the meaning before translation.
- Selecting the appropriate sign according to the context.
- Generate personalised educational content.

This is important because sign language translation is not a process of replacing one word with another; rather, it requires an understanding of meaning, culture and linguistic context.

2.10 Challenges Associated with the Use of Intelligent Sign Language Translation

2.10.1 Differences between sign languages

There is no single universal sign language; rather, it varies from one community to another, such as:

- American Sign Language (ASL).
- British Sign Language (BSL).
- Various Arabic sign languages.

This makes the development of accurate systems a technical and linguistic challenge.

2.10.2 The complexity of sign language

Sign language relies on multiple elements:

- Hand movements.
- The location of the movement.
- Facial expressions.
- Body posture.
- Context.

Therefore, translating it requires advanced artificial intelligence models.

2.10.3 The need for specialised databases

Artificial intelligence systems require large datasets comprising:

- Videos of correct sign language.
- variations in signers.

- diverse educational contexts.

2.10.4 Preserving the role of the teacher and the Deaf community

Artificial intelligence should be used as an aid, whilst respecting the role of special needs teachers and native sign language users in content development.

2.11 Future trends

The future of reading instruction for students with hearing impairments is moving towards integrated systems that combine:

- Intelligent sign language translation.
- Computer vision.
- Large language models.
- Adaptive learning.
- Augmented reality.

This integration could lead to the creation of a smart sign language reading assistant capable of:

- Reading texts and converting them into signs.
- Explaining vocabulary.
- Answering the student's questions.
- Monitoring their progress.
- Adapting the content to their needs.

3. Results

An analysis of the scientific literature on AI-based sign language translation applications in teaching reading to students with hearing impairments has yielded a number of key findings, which are outlined below:

3.1 Sign language translation serves as an effective bridge between written language and visual representation

The literature has shown that AI-based sign language translation systems help to link written texts with the visual representation of sign language, thereby facilitating access to reading material for students with hearing impairments and enhancing their understanding of vocabulary and linguistic structures.

3.2 The diversity of smart translation applications in reading education

Studies have shown that sign language translation applications in reading education are concentrated in three main areas:

- Converting written texts into digital sign language (Text-to-Sign Translation).
- Translating spoken speech into sign language (Speech-to-Sign Translation).
- Converting sign language into written text (Sign-to-Text Translation).

These applications play complementary roles in supporting reading learning within educational settings.

3.3 Integration of Artificial Intelligence Technologies

The results of the analysis showed that the effectiveness of sign language translation increases when integrated with other technologies, such as machine learning, computer vision and large language models, thereby enabling the delivery of educational content that is better tailored to learners' needs.

3.4 Supporting Vocabulary Development and Reading Comprehension

The literature reveals that the use of intelligent sign language translation contributes to enhancing vocabulary acquisition, understanding of meaning, and improved comprehension of texts, by combining linguistic and visual representations of educational content.

3.5 Key Challenges

The results of the analysis revealed a number of challenges that continue to limit the wider adoption of this technology, the most significant of which are:

- Differences in sign languages across countries and communities.
- The complexity of the linguistic and motor structure of sign language.
- The limited availability of specialised educational databases, particularly in Arabic.
- The need to develop more accurate models that take linguistic and cultural context into account.

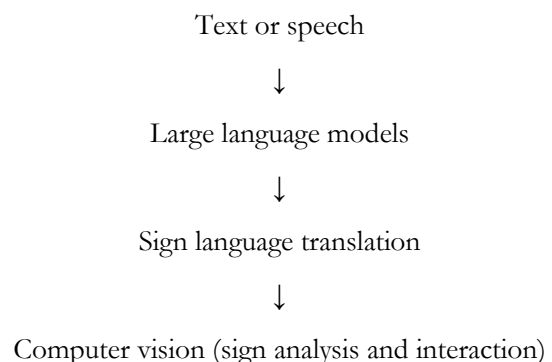
Table (1). Key applications of AI-based sign language translation in reading instruction

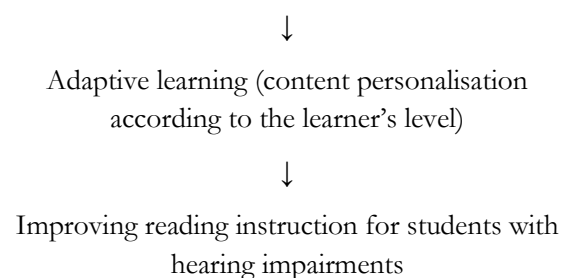
Application	Primary Function	Expected Educational Outcomes
Text-to-Sign Translation	Converts written text into digital sign language using avatars or animated visual representations.	Improves reading comprehension, enhances vocabulary acquisition, and supports literacy development.
Speech-to-Sign Translation	Translates spoken language into sign language in real time.	Facilitates classroom participation, improves access to verbal instruction, and enhances learner engagement.
Sign-to-Text Translation	Converts sign language into written text using computer vision and artificial intelligence technologies.	Supports language expression, strengthens reading and writing skills, and promotes effective communication with teachers and peers.

Figure (1). Conceptual framework for integrating sign language translation with artificial intelligence technologies

Note. This table summarizes the principal applications of AI-based sign language translation and their educational functions in supporting reading instruction for students with hearing impairment, based on recent literature (Bragg et al., 2019; Camgoz et al., 2020).

The relationship between the technologies can be represented as follows:





The results show that AI-based sign language translation is a central component of smart educational environments, and that its integration with other AI technologies provides a foundation for developing more comprehensive and effective models for teaching reading to students with hearing impairments.

4. Discussion

The results of the study indicate that AI-based sign language translation is one of the most promising technologies for developing reading skills among students with hearing impairments, as it establishes a link between written language and visual representation, thereby contributing to enhanced reading comprehension and vocabulary development. These findings are consistent with recent literature, which confirms that the integration of natural language processing, computer vision and linguistic models helps to improve access to educational content and support inclusive learning (Bragg et al., 2019; Camgoz et al., 2020; Kasneci et al., 2023).

The findings highlight the importance of utilising these technologies in the design of smart learning environments that take into account the individual differences among students with hearing impairments. They also provide a theoretical foundation that can be utilised in the development of digital curricula, the training of special education teachers, and the support of educational policies aimed at expanding the use of artificial intelligence technologies in inclusive education.

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However, this study is limited to a theoretical analysis of the scientific literature, without any field testing of the effectiveness of the proposed applications; furthermore, the scarcity of Arabic-language studies in this field may limit the generalisability of the findings. The study therefore recommends conducting empirical research to assess the impact of intelligent sign language translation on the development of reading skills among students with hearing impairments in various educational settings.

5. Conclusion

The study concluded that AI-based sign language translation is one of the most promising technologies for developing reading skills among students with hearing impairments, as it provides an effective link between written language and visual representation, thereby contributing to vocabulary development, enhancing reading comprehension and improving access to educational content. The study also demonstrated that integrating this technology with adaptive learning, computer vision and large language models can help build smarter learning environments that are more inclusive and responsive to learners' needs.

The study recommends developing educational platforms based on intelligent sign language translation, expanding the development of high-quality databases—particularly for Arabic Sign Language—and strengthening collaboration between researchers in artificial intelligence, special education and the deaf community to develop more accurate and effective applications. It also recommends conducting future pilot studies to assess the impact of these technologies on the development of reading and reading comprehension skills among students with hearing impairments, and to compare their effectiveness across different educational settings and academic stages.

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Author Declaration

The authors declare that this manuscript is an original work and has not been published previously, nor is it under consideration for publication elsewhere, either in whole or in part.

The authors further declare that all sources have been appropriately acknowledged and cited in accordance with academic and ethical standards.

The authors confirm that there are no conflicts of interest, financial or otherwise, that could have influenced the research, authorship, or publication of this manuscript.

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