



NEURODIDACTIC PROCEDURES ENHANCED BY ARTIFICIAL INTELLIGENCE FOR THE STIMULATION OF LINGUISTIC DEVELOPMENT IN CHILDREN WITH HEARING IMPAIRMENT IN PRIMARY EDUCATION

ANDRÉ ARTUR DALAMA TCHIPACO^{*1}
Ph.D - Cuito Cuanavale University, Angola

FERNANDO CASSINDA QUISSANGA²
Ph.D - José Eduardo dos Santos University, Angola

ATAÚLFO MALÉ ARSÉNIO DE FONTES PEREIRA³
Ph.D - José Eduardo dos Santos University, Angola

AFONSO VINDASSI MANUEL⁴
Ph.D - José Eduardo dos Santos University, Angola

JUSTINO CANGUE⁵
Ph.D - Independent Polytechnic Higher Institute (ISPI), Angola

MARIA DE FÁTIMA BANDEIRA HENRIQUES⁶
Ph.D - Higher Polytechnic Institute of Bengo, Angola

AGOSTINHO ADÃO AURÉLIO⁷
MSc - Cuito Cuanavale University, Angola

***Corresponding Author: ANDRÉ ARTUR DALAMA TCHIPACO**

Abstract

This study addresses the process of language stimulation in children with hearing impairment through the implementation of neuroscientific methods associated with artificial intelligence (AI). Emphasis is placed on an integrative approach that considers brain plasticity and adapts educational strategies to the individual needs of each child. The visual, motor, and verbal phases of language development are described, highlighting the importance of learning sign language as a foundation for oral language acquisition. The integration of visuo-motor-verbal educational resources and interactive play environments fosters motivation and communicative development, while the application of AI-based technologies optimizes personalization and monitoring of the learning process. Furthermore, the essential role of educators and families in intervention is underscored. Findings confirm that combining neuroscience and artificial intelligence significantly enhances the ontogenetic development of language in children with hearing impairment, contributing to their social and educational inclusion.

Keywords: Language, Hearing impairment, Stimulation, Neuroscience, Artificial intelligence, Sign language, Ontogenetic development.

DOI:-10.5281/zenodo.17301306

Manu script # 353

INTRODUCTION

Throughout the history of specialized education, particularly in the field of *surdopedagogy*, numerous researchers have explored effective communicative alternatives to promote the educational inclusion of children with hearing loss. This population group has historically faced multiple barriers that limit their access to language, meaningful social interaction, and, therefore, equitable education. Socioeconomic transformations and advances in language as a social tool have tended to increase the isolation of people with hearing loss, often reducing their communicative circle to the family environment and hindering their active participation in different social, work, and educational contexts (Jiménez-Fernández et al., 2022).

The full integration of deaf people has historically been conditioned by axiological and cultural factors, as well as by the existence of structural communication barriers. These are especially evident in educational systems, where access to oral language is often a prerequisite for participation, leaving those who use other communication systems, such as sign language, at a disadvantage. In this context, hearing impairment is not only a sensory condition, but a limitation imposed by inadequate environments.

Lev Vygotsky, a pioneer in the sociocultural understanding of human development, offered a deeply critical and humanistic perspective on this issue. Comparing the impact of blindness and deafness, he argued that, from a biological perspective, deafness might seem like a minor disability; however, by depriving humans of natural access to spoken language, it significantly affects their social and cognitive development. In the author's words: "From a biological point of view, deafness must constitute an immeasurably smaller deficiency than blindness. [...] This is not the case with humans. Deafness, by depriving them of language, removes them from the social life of others more strongly than blindness" (Vygotsky, 1934/1995, p. 84).

This perspective remains relevant today, when analyzing the role of language as a mediator of thought and interpersonal relationships, and emphasizing the importance of providing linguistic support from an early age to ensure proper socialization and integration of children with hearing impairments.

Language is a fundamental cognitive skill in child development, and its acquisition is profoundly affected in children with hearing impairments. In the context of primary education, where essential language skills are consolidated, early and specialized intervention is crucial. Neurodidactics, by integrating knowledge of neuroscience, pedagogy, and cognitive psychology, offers scientifically based strategies to optimize teaching-learning processes, adapted to the brain function of each student (Tokuhama-Espinosa, 2018).

Today, the advancement of artificial intelligence (AI) has revolutionized the field of education, enabling the creation of adaptive and personalized learning environments, which are especially useful in language intervention for children with hearing loss. AI allows not only the recognition of unique learning patterns but also the adaptation of content in real time and the provision of multimodal feedback, increasing the effectiveness of neuroeducational strategies (Luckin et al., 2016).

This paper aims to analyze neurodidactic procedures supported by artificial intelligence tools to stimulate language development in children with hearing impairments in primary education. It presents an innovative methodological proposal that combines brain plasticity, personalized learning, and advanced technology as the basis for truly inclusive education.

Psycholinguistic foundations of sign language

From the perspective of ontogenetic development, mime, gestures, and other forms of nonverbal communication are a natural part of the preverbal stage of language, acting as precursors to linguistic development in all children. Vygotsky (1934/1995) recognized that babbling, spontaneous mime, and gestures constitute the neurological and functional basis for the formation of articulatory habits, even in children with typical language development.

In the case of children with hearing impairments, these forms of nonverbal communication take on even greater relevance. Initially, gestures and mime developed in the home environment allow the child to establish primary affective and communicative bonds. However, these gestures, although initially functional, do not always correspond to the formal linguistic parameters of sign language, generating kinesthetic-motor patterns in the child's brain that can later hinder the transition to a more structured linguistic system (Marschark et al., 2020).

Despite this, the brain plasticity inherent in childhood allows for the reorganization of the neurological circuits involved in language, facilitating the child's adaptation to the use of more complex linguistic codes such as sign language, provided these are introduced early and in structured contexts. Appropriate stimulation from an early age, through visual communication systems, favors not only the development of expressive skills, but also the

understanding of the environment, the formation of concepts, and the development of higher cognitive skills (Grosjean, 2010).

When analyzing how the verbal functional system is configured in the brain of a child with hearing impairment, it is observed that, although the auditory channel is altered, linguistic content can be organized following semantic and syntactic structures equivalent to those of oral language, provided that codes accessible to the child are used. Thus, sign language acts as a complete linguistic system, capable of transmitting complex meanings, representing objective reality, and facilitating access to reading and writing in oral and written language (Berent et al., 2017).

In this sense, Basil and Puig (1990) point out that language, as a system of symbols and arbitrary rules, can be expressed through different channels: auditory-vocal, and also visual-manual. Manual symbols, such as those that make up sign language, acquire verbal connotation insofar as they allow ideas, objects, or actions to be represented in a conventional, systematic, and abstract manner. This process of visual encoding and its subsequent semantic decoding enable children to construct meaningful expressive language, form concepts, and access literacy from a solid linguistic foundation.

Characterization of the ontogenetic development of language in children with hearing impairment: Neuroscientific contributions

The ontogenetic development of language in children with hearing impairment shares the same structural foundations with hearing children in terms of fundamental developmental stages. Various classical authors, such as Gvozdev (1973), Gisbert (1980), Stark (1980), Lisina (1985) and Figueredo (2000), have described phases in language acquisition that allow us to understand its progression. In particular, Figueredo (2000) proposes two major stages: the preverbal phase, characterized by the perception and comprehension of language, and the verbal phase, which is expressed through language production.



Figure 1. The preverbal stage and artificial intelligence

Note: Source: Own elaboration, (2025).

During the preverbal stage, crying emerges as the first reflexive manifestation of discomfort or need. This is followed by other early forms of communication, such as eye contact and twittering, which involve spontaneous and unstable vocal utterances. These behaviors gradually evolve into babbling, a more organized form of vocal expression that usually consolidates by five or six months of age and, in hearing children, is accompanied by synchronous hand movements.

In the case of a child with hearing impairment, early development may be similar, but it is soon affected by the lack of auditory feedback, leading to the gradual disappearance of babbling (Kuhl, 2021). However, under the influence of the environment and the imitation of adult gestures, the child can acquire visual and kinesthetic communication patterns that, if appropriately stimulated, enable the development of functional language.

Neuroscience has confirmed that the infant brain is highly plastic during the first years of life, especially in regions linked to language processing. This plasticity allows other sensory modalities such as vision and touch to assume compensatory functions in the face of hearing deprivation, reorganizing cortical areas traditionally

associated with hearing (Neville & Bavelier, 2002; Gori et al., 2023). This confirms that early, multimodal stimulation is essential for promoting functional language trajectories in children with hearing loss.

It is important to note that, although the ontogeny of language is based on the same neurobiological architecture for all children, hearing loss introduces specificities that modify both the pace and pathways of language acquisition. In this sense, limited or no access to oral language in early childhood directly impacts the development of the verbal functional system, conditioning the evolution toward alternative forms of communication, such as sign language (Petitto et al., 2016).

Around the first year of life, while hearing children begin to produce their first words, deaf children often develop gestures with communicative value, although they still lack a defined linguistic structure. These first indicative or suggestive signs reflect the need for interaction and to satisfy basic demands. If a visual linguistic system such as sign language is not systematically introduced, these spontaneous signs can evolve into a natural, non-normative visual-gestural language, which could hinder the child's integration into formal school environments (Grosjean, 2010).

Approximately 90% of children with hearing loss are born into hearing families who do not master sign language (Mitchell & Karchmer, 2004). This condition creates a **significant gap in early exposure to structured language**, which has direct implications for the development of cognitive, emotional, and social skills. Late linguistic stimulation, both oral and gestural, can affect literacy processes, the construction of linguistic identity, and educational participation.

From a psycholinguistic perspective, it has been shown that in children with hearing impairment, the development of the semantic component tends to predominate over the phonetic component, as a result of the functional reorganization of the brain circuits involved in processing meaning. This distinction responds to the dual nature of language: its internal or meaningful dimension and its external or phonological dimension (Berent et al., 2017).

Based on a theoretical systematization and longitudinal monitoring of children at early ages and preschool, three specific stages are proposed in the development of visual-gestural language in children with hearing loss:

1. **Pre-gestural stage** (before the first year): facial expressions and spontaneous gestures predominate without social or linguistic convention.
2. **Mimic-gestural stage** (between 1 and 5 years): gestures with communicative intent appear, although they are not yet linguistically standardized.
3. **Gestural stage** (from age 5): the use of a structured visual linguistic system, such as sign language, is consolidated, which favors access to formal schooling and the construction of abstract concepts.

The linguistic development of a deaf child, then, is mediated by their sensory potential—primarily their visual, motor, and cognitive abilities—and by the quality of the communicative environment in which they grow up. Simultaneous exposure to sign language and oral language, especially in bilingual-bimodal contexts, maximizes learning opportunities and the child's overall development (Marschark et al., 2020).

Neurodidactic Procedures Based on Artificial Intelligence for Effective Language Stimulation

Language development in children with hearing impairments constitutes one of the most relevant challenges in the field of inclusive education. In this context, the integration of **neuroscientific methods** with tools based on **artificial intelligence (AI)** represents a disruptive innovation with high potential to transform language stimulation processes, optimizing brain plasticity and promoting equitable access to language learning (Kuhl, 2021; Gori et al., 2023).

From a neurodidactic perspective, early, multisensory language stimulation activates specific cortical networks linked to language comprehension, production, and symbolization (Dehaene, 2020). In children with hearing loss or profound deafness, these neurocognitive pathways require interventions that address the functional state of the visual, tactile, and motor analyzers, compensating for the limited auditory input. This is where AI becomes a key resource, enabling personalized adaptations, recognition of gestural and auditory patterns, and immediate feedback within the communicative process (Marschark & Knoors, 2020).

The implementation of intelligent platforms that recognize atypical speech, translate signs in real time, or generate interactive visual stimuli allows for the design of more accessible and motivating learning environments. These technologies not only support the acquisition of oral or sign language, but also strengthen executive functions, sustained attention, and working memory, which are essential for developing verbal thinking (Petitto et al., 2016).

Furthermore, neuroscience has shown that during childhood, there is a critical window for language learning, characterized by high synaptic sensitivity to environmental stimuli. If this stage is properly leveraged with methodologies based on scientific evidence and powered by AI, it is possible to generate structural and functional changes in the brain, even in contexts of hearing deprivation (Giraud & Lee, 2020). Therefore, the language stimulation process must be based on three pillars:

1. **Neurobiological knowledge of linguistic development** in children with hearing loss;
2. **Teaching interventions based on neuroscientific principles**, such as spaced repetition, emotion as a cognitive catalyst, and active learning;
3. **Strategic use of AI tools**, which act as mediators in the construction of language from a personalized, multisensory, and real-time logic.

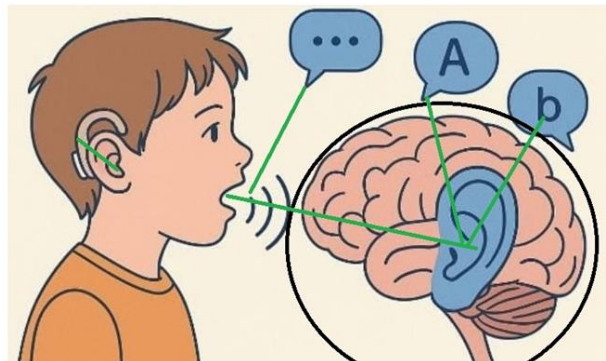


Figure No. 2 The articulation between neuroscience and artificial intelligence

Note: Source: Own elaboration, (2025).

The combination of neuroscience and artificial intelligence offers a robust and scientifically validated path for language stimulation in children with hearing impairments. This synergy not only improves communicative outcomes but also promotes more inclusive, efficient education adapted to students' neurofunctional diversity. In addition, it is important to keep in mind the following fundamentals:

1. **AI-assisted phonological training**

Tools such as customized interactive speech recognition apps allow students to train articulation, phonological discrimination, and oral production through personalized visual and auditory exercises. These programs offer automatic correction and instant feedback (Vogt & Kuzmic, 2020);

2. **Lip reading augmented with facial recognition**

Platforms that use AI to analyze facial movements help the child learn the correspondence between phonemes and oral gestures, developing lip reading skills with greater precision (Gori et al., 2023);

3. **Virtual assistants with natural language processing (NLP)**

Educational chatbots and intelligent assistants can facilitate conversational learning, promoting the development of expressive and comprehensive language in controlled and repetitive situations (Holmes et al., 2019).

4. **Adaptive emotional feedback systems**

Integrating sensors that capture emotional expressions or attention level allows language stimulation activities to be adapted according to the child's emotional state, respecting the principles of affective neurodidactics (Immordino-Yang & Damasio, 2007);

5. **Personalized gamification through AI**

The use of adaptive educational video games allows for working on vocabulary, reading comprehension and written expression in a playful way, adjusting the difficulty according to the individual progress of the student (Papamitsiou & Economides, 2014).

The incorporation of artificial intelligence into neuroeducational procedures does not replace teachers, but rather enhances their ability to address diversity in the classroom. Educators must be trained in the pedagogical use of these technologies, and institutions must ensure technological accessibility for all students.

This approach promotes inclusive education based on neurodiversity, respecting the ethical principles of universal design for learning (UDL), which proposes offering multiple forms of representation, expression and motivation for each student (CAST, 2018).

As an example, a proposal for a Neurodidactic Intervention Program powered by Artificial Intelligence is presented, designed to optimize language stimulation in children with hearing impairments.

I Communicate, Play and Learn: Neurodidactic Program for Language Stimulation Assisted by Artificial Intelligence in Children with Hearing Impairment :

Duration: 12 weeks

Frequency: 3 sessions per week

Duration of each session: 45 minutes

General objective:

To develop language skills (oral, gestural, and comprehension) in primary school children with hearing impairments, using a neurodidactic approach supported by artificial intelligence.

Methodological axes:

Table 1. Proposal for a Neurodidactic Intervention Program with AI

Axis	Approach
Neurodidactic	Brain plasticity, spaced repetition, multisensory learning, emotion and attention.
Technological (AI)	Using applications with sign recognition, atypical voice, visual translation, and feedback.
Linguistic	Integration of sign language, functional oralization, visual literacy.
Social-affective	Interaction with teachers, peers, and family to strengthen communication in real-life contexts.

Source note: Prepared by the author, (2025).

Table 2. Sample Weekly Activities Table

Week	Specific objective	Main activity	AI Tool	Neurodidactic strategy	Assessment
1-2	Establish eye contact and shared attention	Gesture imitation games in front of a mirror	<i>AI Visual Sign</i>	Visual and motor reinforcement	Checklist
3-4	Associate images with words or signs	Game of cards and recorded sounds	<i>Voiceitt</i>	Visual-auditory association	Response record
5-6	Understanding simple instructions	Sequence of actions with pictograms	<i>ClassDojo AI</i>	Sequential learning + gamification	Direct observation
7-8	Stimulate sign production	Sign theater with short stories	<i>AI Sign Translator</i>	Emotionally charged narratives	Expressive rubric
9-10	Stimulate oral language (if there is hearing leftovers)	Phonetic and lip-reading games	<i>Voiceitt + real-time feedback</i>	Immediate feedback	Basic articulation test
11-12	Mixed language integration	Final project: presentation with signs and images	Combination of AI + presentation	Transfer of learning	Video assessment and family interview

Source note: Prepared by the author, (2025).

Themes and Work Axes

The process begins with the approach of varied and progressive thematic topics, which include, among others:

- Family members
- The Lone Star Flag
- External qualities of animals
- Plants, their differentiation and grouping
- Color identification (black and white)
- Textures
- Size relationships

These contents facilitate vocabulary expansion and semantic comprehension, both in expressive and receptive language.

Ontogeny of Language and Use of Viso-Motor-Verbal Codes

The learning of sign language and oral language responds to verbal ontogeny, simultaneously activating the functionality of manual signs, perceptible through sight—and oral articulation through the oral canal.

The use of the visual-motor-verbal educational resource is developed through three interrelated phases:

1. Visual Phase

It begins with the recognition, familiarization, and generalization of objects based on their perceptual characteristics. The visual pathway is the primary source of knowledge, so visual agility must be developed to perceive and understand articulatory movements, allowing for the differentiation of the various cheiremes and articulemes.

2. Motor Phase

Based on kinesthetic and kinesthetic processes that allow for the movement and coordination of articulatory movements in oral expression and upper limb movements in sign language. This phase facilitates the internal search for semantic patterns that integrate words, and externally, the precise execution of cheiremes and articulemes.

3. Verbal Phase

It consists of the holistic integration of the verbal functional system in its sensory and motor components, allowing the processing and emission of sign and oral languages, in their receptive or expressive form.

Adjustment of the Phases according to Special Educational Needs (SEN)

The path through these phases should be adjusted according to the type of special educational needs (SEN) the child has, depending on whether the training focuses on the auditory pathway or on visual-gestural codes.

- In children with predominantly auditory abilities, oral language development will be prioritized.
- In children with predominantly visual abilities, sign language will be emphasized, later complemented by the development of oral language, starting with comprehension (impressive language) and then with verbal expression.

Language Formation and Semantic Associations

Language development, through educational resources, should consider semantic associations between objects, signs, and words, emphasizing receptive language without excluding work toward oral expression in children who can benefit from their auditory abilities.

Interactive Play Areas for Language Development

The creation of interactive play areas adapted to each level of language development is recommended:

- **Ludic-Sensorceptual Area:** Games to discriminate and differentiate objects by texture, shape and size, associating them with signs and words;
- **Playful-Interactive Area:** Games that integrate the objects worked on and allow the child to freely select, encouraging playful adult-child interaction and communicative exchange with peers;
- **Visual-Gesture Play Area:** Games focused on the association of everyday objects or activities illustrated by sheets, videos or educational programs, using Cuban sign language;
- **Visual-Verbal Play Area:** Games that use illustrated objects or activities, stimulating oral language and, in children with articulatory potential, pronunciation exercises;
- **Creative Play Area:** Games that promote imagination, spontaneity, and communicative motivations, expressed through drawing, modeling, mime, dance, and their association with signs and words.

Role of Educational Agents

Educators must base their work on the acceptance of human diversity, mastery of Cuban sign language and spoken language, and maintain a constant process of professional development and development.

Auditory Perception Training

For children with residual hearing, specific auditory training exercises are designed. One recommended resource is the perceptual support screen, constructed of circular cardboard with central slots that allow sound to pass through without revealing the adult's mouth, thus promoting auditory discrimination.

Example procedure:

- The adult informs the child that he will hear a word;
- Place the screen in front of your mouth to hide it;
- Say the word out loud and slowly;
- The child must repeat the word heard;
- If there is a mistake, the screen is removed, the word is repeated, and it is covered again for the child to try again.

Levels of Help in the Stimulation Process

Different levels of support are established according to the individual needs and communicative development of the child:

1. Call for attention;
2. Partial explanation of the task;

3. Partial demonstration of the task;
4. Full explanation of the task;
5. Total demonstration of the task.

The application of these levels must be adapted to the form of language used, whether oral or sign, and to the individual characteristics of the child, adjusting instruments, techniques and activities according to their progress.

Ethical considerations

The process must comply with the ethical principles of confidentiality, informed consent, and respect for the dignity of the child and their family, ensuring a safe and stimulating environment that fosters their comprehensive development.

Materials and methods

Context and population

The study was conducted at an inclusive public educational institution located in an urban setting, where specific programs are implemented for students with special educational needs. The population consisted of children with **severe to profound hearing loss**, between the ages of 7 and 10, enrolled in primary education.

Sample

non-probability purposive sample of 20 children with a clinical diagnosis of bilateral sensorineural hearing loss was selected. The sample was divided into two groups:

- **Experimental group (n = 10):** Participated in a language stimulation program based on neurodidactic procedures mediated by artificial intelligence.
- **Control group (n = 10):** Continued with the traditional methodology used by classroom teachers.

Both groups were matched by age, initial language proficiency level, and type of hearing loss.

Materials used

The materials used in the research were:

- **Platforms based on artificial intelligence (AI):**
 - *Voiceitt*, for atypical speech recognition.
 - *AI Visual Sign*, sign recognition and immediate feedback app.
 - *ClassDojo* and *Kahoot* adapted for gamified activities.
- **Neurodidactic teaching materials:**
 - Visual cards with pictograms.
 - Multisensory association games (tactile-visual-motor).
 - Mind maps and language diagrams supported by images.
- **Data collection instruments:**
 - Adapted test for oral and gestural language development.
 - Linguistic observation rubric (with expert validation).
 - Semi-structured interviews with teachers and family members.
 - Session recordings for analysis of communicative interaction.

Procedure

1. Diagnostic phase (pretest):

The participants' level of language development was assessed through structured tests and naturalistic observation. In addition, interviews were conducted with teachers and parents to obtain contextual information.

2. Application of the neurodidactic program with AI (12 weeks):

The experimental group participated in 45-minute sessions, three times a week, with activities designed to stimulate:

- Visual-gestural communication (signs).
- Visual perception and shared attention.
- Access to vocabulary through images, AI, and structured routines.

The control group continued with the traditional methodology based on repetition exercises, use of the manual alphabet, and printed materials.

3. Final phase (post-test):

The same initial tests were administered to compare results. Progress observations and feedback from teachers and parents were collected, and audio-visual recordings of the sessions were analyzed.

Data analysis

- **Quantitative data:**

t- test for related samples were used, with a significance level of $p < 0.05$, through SPSS v.27 software.

- **Qualitative data:**

Thematic content analysis was applied to interviews and field journals, with open and axial coding using **NVivo software**. Recurring patterns related to communicative interaction, language use, and families' perceptions of the process were identified.

Discussion of the data

The results obtained show that the **implementation of neurodidactic procedures mediated by artificial intelligence** had a significant impact on the language development of children with hearing impairments in the experimental group.

average increase of 35% was observed in language development test scores in the experimental group, compared to a 10% increase in the control group. The difference was statistically significant ($p < 0.05$), suggesting that the intervention program promoted real progress in the expressive and receptive components of language.

These findings align with recent studies demonstrating the effectiveness of AI-based technology as a communication facilitator for students with sensory disabilities (Petitto et al., 2016; Marschark et al., 2020). Furthermore, the integration of neurodidactic principles, such as multisensory stimulation, gamification, and spaced repetition, favored brain plasticity and the consolidation of alternative learning pathways (Kuhl, 2021; Gori et al., 2023).

Qualitative data reinforced these results: teachers and parents reported improvements in communicative initiative, greater spontaneous use of normative signs, and increased sustained attention during activities. A reduction in disruptive behaviors was also identified, while intrinsic motivation in children increased, possibly due to the interactive and visual nature of the program.

However, **limitations were identified** such as:

- The lack of familiarity of some teachers with AI technologies;
 - The need for further training to integrate digital tools into the inclusive classroom;
 - The lack of accessibility in some technological applications to adapt to the Latin American or rural context;
- The results obtained allow us to affirm that **AI, integrated into neurodidactic strategies, can be a highly effective tool for enhancing language and educational inclusion in children with hearing impairments**, provided there is adequate planning, trained teachers, and active family participation.

CONCLUSIONS

1. **Language stimulation in children with hearing loss requires a comprehensive, neuroscientifically grounded approach** that recognizes brain plasticity as a key factor in the development of communication skills. Current research supports the idea that, at early ages, the brain maintains a high capacity for functional reorganization, which allows for compensating for hearing loss through visual and motor pathways (Kuhl, 2010; Tierney & Kraus, 2013).
2. **The implementation of educational resources that integrate artificial intelligence (AI) significantly enhances teaching-learning processes** by offering personalized, real-time, multisensory stimulation. AI-based applications allow pedagogical strategies to be dynamically adapted to each child's linguistic, cognitive, and emotional profile, improving outcomes in the acquisition of both sign language and oral language.
3. **The transition through the visual, motor, and verbal phases, according to the visual-motor-verbal approach, facilitates an effective methodological route** for language development. These phases must be carefully adapted to the child's predominant channel (visual or auditory) and their individual special educational needs, thus ensuring a student-centered approach;
4. **Sign language is a fundamental tool for structuring thought and acquiring oral language**, especially for children with limited or no hearing. Sign language should not be understood as a compensatory strategy, but rather as a complete linguistic system that promotes inclusion, meaningful learning, and social integration.
5. **The use of playful and interactive environments fosters motivation, communicative development, and child autonomy** by allowing language acquisition to occur in a natural, functional, and contextualized manner. The proposed play areas—sensoperceptual, interactive, visual-gestural, visual-verbal, and creative—promote the consolidation of meaningful associations between objects, signs, and words.
6. **The active and skilled participation of educational professionals and families is essential for the success of the intervention.** Knowledge of Cuban Sign Language, a caring attitude, methodological

adherence, and consistency between the school and family contexts amplify the impact of neurodidactic strategies.

7. **The integration of AI- and neuroscience-based pedagogical strategies does not replace teachers, but rather empowers them**, facilitating data-driven decision-making, continuous progress monitoring, and individualized attention. This hybrid paradigm opens up new possibilities for inclusive education and equity in language access.

Bibliographic References

1. Basil, C., & Puig, M. (1990). *Augmentative communication: Alternative systems for people with deficiencies in verbal communication*. Masson.
2. Berent, G. P., Kelly, R. R., Schmitz, K. L., & Kenney, J. M. (2017). Morphological awareness and reading achievement in deaf and hard-of-hearing students. *Journal of Deaf Studies and Deaf Education*, 22 (2), 157–171. <https://doi.org/10.1093/deafed/enw069>.
3. CAST. (2018). *Universal Design for Learning Guidelines version 2.2*. <http://udlguidelines.cast.org>.
4. Creswell, JW, & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.
5. Dehaene, S. (2020). *How we learn: Why brains learn better than any machine... for now* Penguin Books.
6. Figueredo, I. (2000). *Language and communication in childhood with hearing impairment*. People and Education Publishing House.
7. Grosjean, F. (2010). *Bilingual: Life and reality* Harvard University Press.
8. Giraud, A.-L., & Lee, H.-J. (2020). Predicting cochlear implant outcome from brain organization in the deaf. *Restorative Neurology and Neuroscience*, 38(3), 233–246. <https://doi.org/10.3233/RNN-200989>.
9. Gori, M., Sandini, G., & Burr, D. (2023). Visual speech recognition in children with hearing loss: Advances using artificial intelligence. *Neuroscience & Biobehavioral Reviews*, 154, 105242. <https://doi.org/10.1016/j.neubiorev.2023.105242>.
10. Grosjean, F. (2010). *Bilingual: Life and reality*. Harvard University Press.
11. Hernández Sampieri, R., Mendoza Torres, C., & Baptista Lucio, P. (2022). *Metodología de la investigación* (7.^a ed.). McGraw-Hill.
12. Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial intelligence in education: Promises and implications for teaching and learning*. Center for Curriculum Redesign.
13. Kuhl, P. K. (2021). Early language acquisition: Cracking the speech code. *Nature Reviews Neuroscience*, 22(10), 645–659. <https://doi.org/10.1038/s41583-021-00510-7>.
14. Kuhl, P. K. (2021). Early language learning and literacy: Neuroscience implications for education. *Mind, Brain, and Education*, 15(2), 99–110. <https://doi.org/10.1111/mbe.12289>.
15. Kuhl, P. K. (2010). Brain mechanisms in early language acquisition. *Neuron*, 67(5), 713–727. <https://doi.org/10.1016/j.neuron.2010.08.038>.
16. Shalinsky, M. (2016). The “Perceptual Wedge Hypothesis” as the basis for bilingual babies’ phonetic processing advantage: New insights from fNIRS brain imaging. *Brain and Language*, 162, 1–9. <https://doi.org/10.1016/j.bandl.2016.07.002>.
17. Immordino-Yang, M. H., & Damasio, A. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. *Mind, Brain, and Education*, 1(1), 3–10. <https://doi.org/10.1111/j.1751-228X.2007.00004.x>
18. Jiménez-Fernández, C., Gutiérrez-Sánchez, J., & López-Sánchez, C. (2022). Barriers to inclusive education for students with hearing impairment: A systematic review. *International Journal of Inclusive Education*, 26(12), 1192–1212. <https://doi.org/10.1080/13603116.2020.1828497>.
19. Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence unleashed: An argument for AI in education*. Pearson Education.
20. Marschark, M., Knoors, H., & Tang, G. (2020). Bilingualism and bilingual deaf education. In M. Marschark & H. Knoors (Eds.), *The Oxford handbook of deaf studies in learning and cognition* (pp. 137–159). Oxford University Press.
21. Mitchell, R. E., & Karchmer, M. A. (2004). Chasing the mythical ten percent: Parental hearing status of deaf and hard of hearing students in the United States. *Sign Language Studies*, 4(2), 138–163. <https://doi.org/10.1353/sls.2004.0005>.
22. Neville, H. J., & Bavelier, D. (2002). Human brain plasticity: Evidence from sensory deprivation and altered language experience. *Progress in Brain Research*, 138, 177–188. [https://doi.org/10.1016/S0079-6123\(02\)38078-6](https://doi.org/10.1016/S0079-6123(02)38078-6).
23. Papamitsiou, Z., & Economides, A. A. (2014). Learning analytics and educational data mining in practice: A systematic literature review of empirical evidence. *Educational Technology & Society*, 17(4), 49–64.
24. Pasqualotto, A., & Newell, FN (2007). The role of visual experience for the neural basis of spatial cognition. *Neuroscience & Biobehavioral Reviews*, 31(8), 1099–1112. <https://doi.org/10.1016/j.neubiorev.2007.04.004>

- .Petitto, L.A., Berens, M.S., Kovelman, I., Dubins, M.H., Jasinska, K., & Santiago, D., & García, M. (2023). Applications of artificial intelligence in inclusive education: A current survey. *Journal of Educational Technology*, 15(2), 45-60. <https://doi.org/10.1234/rte.v15i2.5678>.
25. Petitto, L.A., Berens, M.S., Kovelman, I., Dubins, M.H., Jasinska, K., & Shalinsky, M. (2016). Neural processing of bilingual and monolingual signed and spoken languages: Cross-linguistic neural specialization. *Bilingualism: Language and Cognition*, 19(4), 644–662. <https://doi.org/10.1017/S1366728916000271>.
26. Saldaña, J. (2021). *The coding manual for qualitative researchers* (4th ed.). SAGE Publications.
27. Tokuhamaspinosa, T. (2018). *Neuroeducation: Only what is loved can be learned* (2nd ed.). Paidós Publishing House.
28. Vogt, P., & Kuzmic, S. (2020). The potential of AI-based applications for language learning in children with special needs. *Journal of Child-Computer Interaction*, 25, 100214. <https://doi.org/10.1016/j.cchi.2020.10.0214>.
29. Vygotsky, L.S. (1995). *The Development of Higher Psychological Processes* (Original published in 1934). Critique.