

THE IMPACT OF ARTIFICIAL INTELLIGENCE TECHNIQUES ON THE DEVELOPMENT OF SPATIAL PREPOSITIONS (HÜRÜF AL-MA'ĀNI) IN DEAF CHILDREN WITH COCHLEAR IMPLANTS

 Hocine Nouani¹  Sihem Karboua²  Lamis Benchabane³

¹ Laboratory of Analytical Anthropology and Psychopathology, University of Algiers 2 (Algeria),
hocine.nouani@univ-alger2.dz

² University of Tipaza (Algeria),
karboua.sihem@univ-tipaza.dz

³ Laboratory of Analytical Anthropology and Psychopathology, University of Algiers 2 (Algeria),
lamisse.benchabane@univ-alger2.dz

Abstract: This study aims to examine the impact of using artificial intelligence technologies in developing the acquisition of spatial prepositions (HÜRÜF AL-MA'ĀNI) among deaf children with cochlear implants. To achieve the research objectives, three operational procedures were adopted in a systematic and structured manner. The first involved a clinical diagnostic assessment to differentiate and control variables, using an audiometric speech test to ensure the accuracy of participant selection and the homogeneity of the study sample. The second was an empirical experimental investigation to test the hypotheses, employing a one-group pretest-posttest experimental design to explore the linkage between perspectives according to Jean Piaget. This phase incorporated the application of an educational program using artificial intelligence technologies through an intelligent robot proposed in the study, designed to provide interactive learning experiences and facilitate the acquisition of targeted linguistic concepts. The third procedure was a statistical analysis to process the obtained results and determine the significance of the observed differences between measurements. The study was conducted on a sample of seven (07) deaf children with cochlear implants, aged 10 years, enrolled in a specialized school for the deaf. The findings revealed statistically significant differences between the pre-test and post-test results in favor of the post-test, indicating the effectiveness of the proposed program applied to the study group. This confirms the role of artificial intelligence techniques, particularly smart robots, in fostering the acquisition of spatial prepositions in deaf children with cochlear implants. The study further underscored the importance of integrating modern technologies, such as automated devices and robotics, into the education and learning processes of individuals with special needs, particularly those with hearing impairments, while highlighting their potential contribution to improving educational outcomes and supporting language development.

Keywords: Artificial intelligence techniques; cochlear implants; deaf children; spatial prepositions (hürüf al-ma'āni); language development

How to cite this article:

Nouani, H., Karboua, S., & Benchabane, L. (2026). The impact of artificial intelligence techniques on the development of spatial prepositions (hürüf al-ma'āni) in deaf children with cochlear implants. *Journal of Studies in Language, Culture, and Society (JSLCS)*, 9(2), 160-175

¹ Corresponding author: Karboua Sihem Authors' ORCID ID: <https://orcid.org/0009-0009-4409-1593>

1. Introduction

The concept of space is fundamental to a child's healthy development, as language itself operates along two axes: the temporal and the spatial (Nouani, 2018). This corresponds to what classical Arab scholars referred to as the concepts of structure and connection (Hadj Salah, 2008), later reaffirmed by De Saussure (1994) through the notions of the syntagmatic and paradigmatic axes. The spatial axis encompasses the perception of spatial relationships, directions, and dimensions, with language playing a crucial role in acquiring these concepts. This linguistic framework enables children to name and designate locations, objects, and spatial relations, relying on mental representations of space through spatial markers such as right-left and front-back to fully navigate and control their environment.

Spatial perception is inherently abstract and challenging to define. Piaget conceptualized space as the ability to coordinate movements, in contrast to time, which he defined as the ability to coordinate speeds. According to Piaget, space is not merely the perception of containers but rather the perception of contents or more precisely, the perception of objects themselves. Space, therefore, is an organized and coordinated system of movements that allows for the continuous reconstruction of consistent forms. It constitutes a network of relationships among perceived or constructed objects, as well as the set of relations individuals use to construct, perceive, and understand these objects, ultimately fostering higher cognitive abilities leading to what Piaget termed conceptual intelligence (Piaget & Inhelder, 1956).

According to Arab linguists, these linguistic elements belong to the category of function words, which are considered non-autonomous linguistic units. They encompass function words, defective verbs, invariable nouns, and grammatical particles, all of which contribute additional semantic value to nouns and verbs, extending beyond their inherent lexical (Hadj Salah, 2008). Such elements require contextual support to manifest their function, as they lack inherent lexical meaning or inflectional patterns of their own.

To remain within the scope of our study, we will focus specifically on the function word related to spatial markers—an invariable noun that denotes a place or, more precisely, a spatial reference (El-Dahdah, 1993, p. 64). Since function words do not carry meaning independently and require a noun or verb for their semantic realization, they are notoriously difficult for children to acquire. This difficulty is further exacerbated for individuals with various disabilities that affect typical developmental processes, particularly deaf children, as their auditory impairment leads to significant communication challenges.

Hearing is the primary modality for language acquisition and a crucial tool for communication, serving as the main channel through which individuals receive information from their environment. Consequently, hearing impairment presents a major obstacle to a child's development from an early age. Profound deafness represents the most severe degree of hearing impairment, wherein individuals lose the ability to perceive spoken language, even with the assistance of various auditory aids.

Modern technology plays a significant role in the field of hearing impairment, by developing tools to enhance speech skills and linguistic growth, utilizing widespread techniques in this field such as auditory processing technology and cochlear implants. In this context, the study conducted by Badrina (2014) explored the acquisition of spatial linguistic units in deaf children and their relationship to cognitive processes. The researcher compared two groups: deaf children with cochlear implants and those using conventional hearing aids. Several assessment tools were employed, including the Pierart (1978) Linguistic Units Test, the Benton (2008) Visual Retention Test to evaluate visual memory in deaf children, and the Categorization Analysis Subtest from the Differentiated Scale of Cognitive Abilities (EDEIR).

The study involved 12 deaf children—six with conventional hearing aids and six with cochlear implants. The findings revealed significant differences between the two groups in acquiring spatial linguistic units, both in comprehension and production. Deaf children with conventional hearing aids demonstrated slower acquisition, particularly for complex spatial markers that require advanced spatial projection skills. Additionally, these children tended to rely more on manual gestures as a primary means of expression.

Similarly, Bizat (2021) study examined the relationship between mental representation and spatial structure in deaf children. The researcher administered a series of tests, including mental representation tasks at various developmental stages, Piaget's Three Mountains Task, the Length Conservation Test, and the Kohs Block Design Test, to a sample of 60 deaf children aged 8 to 10 years. The participants were divided into two groups: one consisting of deaf children with cochlear implants and the other of those using conventional hearing aids. After applying the methodological procedures, the study concluded that there is a correlation between mental representation and spatial structure in deaf children. The results indicated that the more refined the acquisition of mental representation, the better the development of spatial representation.

We can say that, thanks to these technologies—particularly cochlear implantation—deaf children have become capable of perceiving various sounds, which has significantly enhanced their ability to communicate. With the advancement of cochlear implantation technologies and the growing interest in integrating modern technologies into the educational process and specialized teaching methods in recent years, artificial intelligence technologies have recently emerged as a valuable tool in the field of special education and speech therapy. These technologies take the form of machines or robots composed of multiple components that perform specific tasks by following a set of pre-programmed instructions stored in the device's electronic memory. They are characterized primarily by repetition and perseverance. A series of commands is designed using specialized computer software and linked to the robotic device, with the primary aim of helping children develop cognitive skills and mathematical thinking at an early age. Additionally, these technologies foster higher-order thinking skills such as creativity and problem-solving by enhancing time management and organizational abilities.

Based on recent studies on the adoption of robotic devices in education in general and for individuals with hearing impairments in particular, we find the study by Akalin, Uluer, Kose and Ince (2013) on human-robot communication with users through sign language. This study focuses on an interactive game based on sign language, designed to highlight the preliminary findings of an ongoing project that employs humanoid robots as sign language instructors for children who struggle with communication, including children with hearing impairments and those with autism. The study's methodology involved presenting an interactive sign language-based game between a humanoid robot and a participant. The game was structured in two phases: the first phase involved learning sign language through imitation, while the second phase assessed the learner's signs through an interactive game. The study concluded that participants demonstrated improvements in imitation skills, turn-taking, and the semantic understanding of signs.

Additionally, the study by Ioannou and Andreeva (2019), examined the use of intelligent robotic devices as a tool for therapy and education among children with hearing impairments. This group included both children with partial hearing loss and deaf children equipped with hearing aids or cochlear implants. The researchers sought to evaluate the effectiveness of using intelligent robotic devices in enhancing the linguistic, cognitive, and communication abilities of the study participants. The results confirmed significant progress

in language skills, improvements in listening and speech abilities, and enhanced attention and concentration following therapy sessions that incorporated the intelligent robotic device.

Furthermore, the study by Ammar (2021) concluded that educational robots have a positive impact on academic achievement in the context of digital transformation. Similarly, the study conducted by Al-Akhtar and Al-Freih (2022) highlighted that integrating educational robots within digital transformation strategies not only enhances academic achievement or innovative skills separately but also provides a comprehensive educational solution that enriches the overall learning experience across various domains.

This suggests that the use of educational robots extends beyond mere technological advancements to become a fundamental tool for achieving inclusive education, particularly for groups facing learning challenges, such as deaf children.

Additionally, the study by Brainin, Shamir, and Eden (2022), titled *Programming Robots Contributes to Enhancing Language and Spatial Abilities*, confirmed that interactive robot programming plays a significant role in developing language and cognitive skills in children with learning difficulties. The high effectiveness demonstrated in this study suggests that deaf children with cochlear implants may respond positively to robot-assisted learning. This is attributed to the partial auditory perception provided by the implant, which facilitates the integration of auditory and visual signals.

Furthermore, the study by Uluer, Kose, Gumuslus and Barkana (2023) emphasized the effectiveness of using emotional robots with children who have hearing impairments.

The most recent study in this field, within Local research, our study Benchabane and Nouani (2024a-2024b) concluded that deaf children face difficulties in structuring spatial landmarks and projective concepts, and that early intervention following cochlear implantation plays a positive role in language development and cognitive ability enhancement. Secondly, it highlighted the importance of integrating modern technologies, such as robots, into learning.

In international research, Khasawneh (2024) study, titled *The Effective Role of Educational Robots in Enhancing Cognitive Skills Among Students with Hearing Impairments*, emphasized that educational robots provide an interactive learning environment that surpasses the limitations of traditional teaching methods.

AI-based adaptive learning environments have been shown to improve language learning outcomes through personalized instruction and real-time feedback (Dekhakhena, 2025). Recent research suggests that AI chatbots can effectively foster intercultural awareness and communication skills among EFL learners (Sellami, 2025).

Based on previous studies that have addressed aspects of our research topic, we observed that most of them focused on the use of artificial intelligence technologies in training and educational programs involving robotic devices. These studies explored their role in enhancing spatial and geometric concepts among children with hearing impairments in general. Meanwhile, research on the concept of spatial representation has primarily compared how this concept is acquired between typically developing children on one hand, and deaf children using conventional hearing aids or cochlear implants on the other.

However, our study specifically examines the concept of spatial prepositions among deaf children with cochlear implants and the role of artificial intelligence technologies—represented by a proposed intelligent robot—in enhancing their acquisition of this concept. Our approach differs from previous studies by focusing on this particular aspect of language learning. The integration of artificial intelligence technologies in teaching deaf children with

cochlear implants presents several challenges, particularly in reinforcing their understanding of spatial prepositions. At the same time, it serves as a modern tool in clinical and educational interventions for this group, offering potential solutions to challenges related to time efficiency, effort optimization, and improving learning outcomes.

1.1 Research Problem

Based on the above, we propose the following general research question:

- Is the use of artificial intelligence technologies effective in developing the understanding of spatial prepositions among deaf children with cochlear implants?

As an operational hypothesis for this research question, we propose the following hypothesis:

1.2 Research Hypothesis

There are statistically significant differences between the pre-test and post-test measurements of the perspective-linking test results after the application of artificial intelligence technologies (the proposed intelligent robot), favoring the post-test measurement.

1.3 Research Objectives

The primary objective of this study is to highlight the role of integrating artificial intelligence technologies into educational methods to enhance the acquisition of spatial prepositions among deaf children with cochlear implants. Additionally, the study seeks to align with contemporary educational advancements by shedding light on educational robots as a facet of artificial intelligence and their potential integration into the care and education of deaf children.

Specifically, the study aims to explore the feasibility of incorporating educational robots into rehabilitation and teaching sessions, particularly during assessment sessions conducted by clinical practitioners, including speech therapists and special education specialists. By doing so, the research paves the way for further exploration, development, and innovation in modern tools and techniques that can enhance the learning, rehabilitation, and therapeutic interventions for deaf children.

2. Theoretical Framework

2.1 Spatial Propositions (hürüf al-ma'āni)

Spatial prepositions are prominently present in both spoken and written language. This is due to their lack of inherent semantic content, as they remain abstract and do not conform to morphological rules such as form or weight. It is important to note that the development of spatial concepts is contingent upon the child's cognitive growth and intelligence. Moreover, these concepts are closely linked to the referential function of language, as described by Jakobson.

Language, by its very nature, serves as a system of reference: proper names refer to individuals, time expressions indicate temporal points, place names denote locations, and verbs signal actions and events. This referential function underscores the fundamental importance of acquiring spatial prepositions, as they are integral to comprehension and communication. According to Bronckart (1981), this acquisition results from two types of developmental processes:

- Individual development related to sensorimotor intelligence, resulting in the growth of conceptual abilities and representations, as outlined by Piaget.

- Social development related to the interactive cycle, which occurs through social and cultural exchanges—specifically language—according to Vygotsky (1985), leading to the development of communication abilities.

From this perspective, the acquisition of the linguistic sign, according to Saussure (1916, 1994), is explained by the integration of these two developmental processes. The first facilitates the acquisition of the signified through cognitive concepts, while the second enables the acquisition of the signifier through verbal expression in linguistic exchanges. The connection between the signifier and the signified develops alongside the growth of symbolic function, as described by Piaget (Nouani, 2018, pp. 75-76).

A child's interaction with spatial environments originates from two sources of knowledge:

- A source linked to the child's activity and interaction with the physical environment during the sensorimotor stage, as described by Piaget.
- A source connected to the environment through language, as proposed by Vygotsky (1984) and Bruner (1983).

Through exploratory movements and direct manipulation of objects, children gradually acquire an understanding of space. This space consists of four interrelated domains, each forming paired spatial oppositions, such as front/back and right/left. Mastering these spatial determinants requires an organized spatial framework, which takes an extended period to develop, progressing from birth to adolescence.

According to Piaget's theory of cognitive development, the child's spatial perception develops through three fundamental stages, each representing a distinct cognitive organization of spatial relationships:

- **Topological Space:** In this initial stage, the child focuses on the fundamental properties of objects without considering precise dimensions or geometric relationships. The child perceives concepts such as proximity, separation, order, and enclosure. This perception treats shapes as flexible, changeable entities, disregarding straight lines, angles, and fixed dimensions.
- **Projective Space:** As cognitive development progresses, the child begins to recognize the constancy of object shapes despite changes in orientation. In this stage, the child starts to understand how perspectives shift based on their movement relative to objects. The concept of egocentric projection evolves into allocentric projection, allowing the child to visualize spatial relationships from another person's perspective.
- **Euclidean Space:** In this advanced stage, the child acquires the ability to perceive and understand metric and geometric relationships. They become capable of recognizing angles in geometric shapes and maintaining an awareness of physical measurements, even when objects appear to change shape. This development is evident in conservation experiments, where the child realizes that the quantity of a substance remains constant despite changes in its form.

It is important to note that these stages develop gradually and in an overlapping manner rather than following a strict linear progression. A child's spatial understanding is continuously constructed through interaction with their environment, leading to increasingly complex cognitive structures. This developmental process reflects the principle of equilibration, which is central to Piaget's theory. The child constantly seeks to achieve a balance between assimilation and accommodation in their understanding of spatial concepts (Piaget & Inhelder, 1956).

2.2 Artificial Intelligence Technologies

The learning process for individuals with learning difficulties, regardless of their category, relies on training in cognitive strategies that play a role in enhancing the cognitive processing of sensory information input to the brain (Karboua & Nouani, 2020). Artificial intelligence technologies are utilized in the development and innovation of educational robotic devices or humanoid robots, which are employed in educational environments to engage students and children in learning robotic programming or basic programming concepts through simple control and guidance mechanisms. According to Plauska and Damasevicius (2014), educational robotic devices serve as an educational tool that provides learners with an explicit representation of the knowledge contained in textbooks. These devices contribute to greater engagement in the learning process, enhance academic integration, and offer immediate feedback (Ammar, 2021, p. 04).

Operationally, artificial intelligence technologies can be defined as an innovative technology that leverages modern advancements to make learning interactive and engaging for children. Designed for both typically developing children and children with special needs who may struggle with traditional learning methods, the educational technology in this study consists of a programmable intelligent robot that is user-friendly and can be programmed using a simple application or a remote control. The robot is capable of moving in four directions, producing sounds and light signals, and can be utilized in various educational settings, including schools, centers, and homes.

2.3 Hearing Impairment

Hearing impairment refers to partial deficiency or total loss of auditory perception, resulting from damage either to the auditory system, including the different parts of the ear, or to the auditory nerve. This damage can range from mild conditions, such as the accumulation of earwax, which causes blockage of the external auditory canal, to severe damage affecting the inner ear structures. Consequently, hearing impairment encompasses all forms of hearing dysfunction, varying in degree from mild hearing loss to severe or profound deafness.

Hearing impairment has a negative impact on language development. A deaf child may also become mute if they do not receive effective specialized training, primarily due to the absence of linguistic modeling and lack of auditory feedback when producing sounds. Additionally, insufficient linguistic reinforcement from others further hinders language acquisition (Rikza, 2014, pp. 20-41).

2.4 Cochlear Implant

A cochlear implant is an electronic device used to enhance hearing in individuals with severe to profound sensorineural hearing loss. It is surgically implanted in the inner ear, where it converts sound into electrical signals that are transmitted to the brain via the auditory nerve. This device aids in restoring partial hearing abilities and improving language comprehension, particularly when combined with early intervention by speech and language specialists (Abdel-Baset, 2022).

Additionally, the cochlear implant enables auditory perception and enhances verbal communication abilities for individuals with severe or profound hearing loss, especially those who cannot benefit from conventional hearing aids due to the extent of their impairment.

3. Field Framework of the Study

3.1 Research Methodology

This study adopted a quasi-experimental methodology, relying on a single experimental group with pre-test and post-test measurements of the selected assessment. The intervention consisted of training using an educational robot, implemented between the pre-test and post-test phases.

3.2 Study Group

The study group consisted of seven (07) deaf children with cochlear implants, all aged 10 years. Gender was not considered a variable in this study.

3.3 Study Boundaries

The study group was selected from the School for Young Deaf Children in the Wilaya of Constantine. The educational robot was used as part of the intervention, with two sessions per week over a period of three months.

3.4 Research Instruments

This study incorporated three procedural approaches, applied sequentially:

- First Procedure (Clinical Approach): The primary objective was to control the study variables, particularly those related to the research group. It was necessary to test the implanted devices (cochlear implants) by conducting speech audiometry on the study participants. This technique ensures that the implanted device is functioning correctly and that the recipient accurately perceives auditory stimuli (intelligibility). It also checks that the hearing impairment has been effectively addressed, allowing the individual to receive and interpret auditory signals clearly.
- Second Procedure (Empirical-Experimental Approach): The objective of this approach was to test the hypotheses and field procedures by administering two instruments:
 - A pre-test and post-test, specifically Piaget's Perspective-Taking Test.
 - A training tool, represented by the educational robot.

Below is a detailed presentation of the instruments used in this approach:

3.4.1 Piaget's Perspective-Taking Test

Given the nature of this study, which focuses on spatial prepositions, we applied the Perspective-Taking Test to the study group. This instrument was initially designed by Jean Piaget, consisting of a model board featuring miniature mountains with a small river running through them. The child was asked to respond based on their perceptions of this small-scale model.

In 1968, Monique Laurendeau and Adrian Pinard developed a new version of this perspective-taking study model, constructing it from cardboard and a paper base. The Perspective-Taking Test aims to identify the fundamental stages of the progressive development of projective space. Additionally, it is characterized by its requirement for the child to simultaneously process two projection dimensions (right-left and front-back).

A. Test Components

The experimental apparatus for the test consists of the following elements:

- A green cardboard square measuring 52 cm per side, used as a base on which the three cones are placed. The base is divided into four smaller squares using adhesive tape.
- Three cardboard cones representing three mountains of varying sizes, which must be placed in their designated positions on the green base as follows:
 - The large cone, which is red, has a diameter of 20 cm and an axis height of 11.5 cm.
 - The medium-sized cone, which is blue, has a diameter of 14 cm and a height of 7.5 cm.
 - The small cone, which is yellow, has a diameter of 9 cm and a height of 5 cm.
- A small figurine, approximately 3 cm tall, which can be made of clay or plastic.
- A set of nine cards, each measuring 18 x 14 cm, representing different viewpoints of an external observer. Among these, seven cards correspond to actual perspectives (labeled A, B, C, D, E, F, G), while two cards depict impossible hypothetical perspectives (labeled H, I).

3.4.2 Scoring Method

The scoring method for the Perspective-Taking Test follows a binary evaluation system, where each response is classified as either correct or incorrect. If the child provides a correct answer, they receive one point; if the answer is incorrect, they receive zero points.

- In the first section of the test, the child's answer is considered correct if they successfully identify the image that corresponds exactly to the small figurine's perspective while rejecting the remaining cards. The child can earn a maximum of three points if all responses are correct.
- In the second section of the test, the child's answers are considered correct in the first four tasks when they place the small figurine in the appropriate location that matches the perspective shown in the proposed card or in a nearby position that does not significantly alter the figurine's viewpoint relative to the image.
- In the fifth task (Card I), success is determined by the child's ability to recognize the impossibility of placing the figurine in the position represented by the hypothetical card.
- A maximum of five points can be earned if all responses are correct.
- Overall, the highest possible score a child can achieve in this test is 8 points.

3.4.3 Test Administration Procedure

A. The test consists of two phases

- Phase 1: The "Recognition Technique", which involves the use of five cards (E, C, F, B, A).
- Phase 2: The "Figurine Placement Technique", which involves the use of five cards (F, C, B, E, I).

B. The experimental apparatus is placed on a table, ensuring that:

- The yellow cone is positioned to the right.
- The red cone is placed behind the yellow mountain.
- The blue mountain is positioned to the right of the yellow cone.

This setup is based on the child's perspective, as they are seated in a chair directly facing the described mountains in position A.

Before administering the test for the first time, the researcher conducted a simple preliminary training exercise to ensure that the child fully understands the test's principle. This training example involves placing the small figurine in position A, which perfectly aligns with the child's own perspective. The child is then asked to select the appropriate image or card that represents what the figurine sees, choosing between Card A and Card D.

However, the children in the study were unable to provide the correct answer for this training exercise and experienced significant difficulty in understanding subsequent questions related to Phase 1 (Recognition Technique).

The Perspective-Taking Test is divided into two parts

- Part 1: A task is considered successful when the child correctly identifies the card that matches the figurine's perspective and rejects all other cards.
- Part 2: The first four tasks are considered successful if the child correctly places the figurine in the exact location that corresponds to the proposed card's perspective, or at least in a nearby position where the observed viewpoint remains consistent with the one presented on the card.
- For the fifth task (Card I), success is based on the child's ability to recognize the impossibility of placing the figurine in the position that would match the perspective shown on the card.

C. Instruction

After placing the three cones on the green square (in the designated positions marked by circles), the process is explained to the child as follows:

"Now, we are going to play with these mountains. Look here—I have three mountains: a red mountain, which is the largest, a blue mountain, which is smaller than the red one, and a yellow mountain, which is the smallest of all. I also have a small figurine (presenting the plastic or clay figurine) and look—it is very small, while the mountains are much bigger than it. The figurine is going to take a walk around these mountains, and your task is to figure out what the images captured from this figurine's perspective might look like" (Khrief, 2007).

D. Adapting the Instruction

We attempted to modify and simplify the instruction to align with the communication methods used with deaf children with cochlear implants. Some phrases were removed, while others were adjusted without compromising the intended goal of administering the test.

3.4.2 The Educational Program (AI-Based Intelligent Robot)

Among the researchers who have explored the design of an educational and pedagogical robot, one notable initiative is a pioneering experiment in Algeria by the company "Al-Jazari Robotics." This company developed an educational robot named "KIDZOBOT" for children aged 5 to 13 years, offering various applications designed to simplify the concepts and principles of computer programming.

The chief executive officer (CEO) of the startup, Engineer Houssam-Eddine Belkour, explained to the Algerian News Agency that this project aims to integrate modern educational tools as a complementary activity to traditional teaching, addressing students' learning needs through play and entertainment. He emphasized that the project seeks to promote reading and facilitate learning in science and technology through diverse educational modules, ranging from letters and words to world landmarks, drawing, design, and ornamentation (Algérie Presse Service, 2021).

The "KIDZOBOT" program has received multiple recognitions and is currently used in schools and preschools across Tunisia, the United Arab Emirates, Saudi Arabia, and even Norway. In Algeria, it is implemented in eight provinces, including Constantine.

The "KIDZOBOT" educational robot consists of three main components:

A. Electronic Components

- A Bluetooth processor
- A rechargeable battery
- A power button
- An infrared signal receiver

B. Mechanical Components

- Two wheels with rubber traction for movement
- A freewheel for balance
- A buzzer for sound emission
- An outer wooden frame equipped with LED lights

C. Software Components

This refers to the programming method used for the "KIDZOBOT" educational robot, which can be done in two ways:

- Using a dedicated smartphone application ("KIDZOBOT APPLICATION"), allowing users to control and program the robot via Bluetooth.
- Using a remote control, which serves as an alternative to the smartphone while maintaining the same programming format.

This programming approach follows the "step-by-step" model, using directional arrows (right, left, forward, backward) placed on a precisely measured and calibrated puzzle-based interface to guide the robot's movement.

Program Implementation Procedures

During the first session, we invited the children (study group) to the office of the speech therapist, with the assistance of a psychologist who has over 20 years of experience working with children with hearing impairments.

We placed the robot in front of them and attempted to explain what it is and how it functions. Then, we provided each child with a turn to experiment using the remote control, allowing them to freely test the buttons and discover how to maneuver the robot.

We then demonstrated direct control using all commands, with a particular focus on the "Step Forward" command. The robot was placed on a table, and we positioned a target at the opposite end. Each child, in turn, was asked to control the robot to reach the target using the "Step Forward" instruction.

The children's response was generally positive, as the robot is easy to use and can be programmed in a simple manner.

- **Third Procedure (Statistical Treatment):** The objective of this procedural is to analyze the results and data using appropriate statistical procedures. We employed the T-test for paired samples, which is suitable for measuring differences in a single-group design, utilizing the Statistical Package for the Social Sciences (SPSS) for data analysis.

Below is a presentation of the results obtained from this analysis, followed by their interpretation and discussion in relation to the study hypothesis.

4. Results and Discussion

The study hypothesis states:

"There are statistically significant differences between the pre-test and post-test measurements of the Perspective-Taking Test results, following the application of artificial intelligence technologies (the proposed program), in favor of the post-test measurement."

The following table presents the statistical results:

Table 1.

Results of the T-Test Comparing Pre-Test and Post-Test Scores on the Perspective-Taking Test.

Measurements	Mean	Standard Deviation	Mean Difference	"T" Value	Degrees of Freedom (df)	Sig. (Bilateral)
Pre-test	4.14	1.21	2.57	4.87	6	0.03
Post-test	6.71	0.95				

N=7 / df= 6 / p-value = 0.03

From the table, we observe that the T-value is 4.86, with a two-tailed significance value of 0.03, which is less than 0.05. This indicates that the differences in the results are statistically significant at the 0.05 significance level ($\alpha = 0.05$).

These findings demonstrate that the post-test measurements outperformed the pre-test measurements, thereby confirming the validity of the study hypothesis.

The findings of the current study reveal a notable improvement in the acquisition of spatial prepositions among deaf children with cochlear implants. The statistical analysis indicated a significant increase in the mean scores of the group, rising from 4.14 in the pre-test to 6.71 in the post-test.

This quantitative improvement aligns with the findings of Bizat (2021), which emphasized the importance of mental representation in the development of spatial structure in deaf children. The educational robot functions as a technological mediator that supports and enhances this mental representation.

These positive results can also be interpreted in light of the study by Ioannou and Andreeva (2019), which demonstrated that the use of intelligent robots significantly enhances therapeutic outcomes for children with hearing impairments.

These positive results can also be interpreted in light of Khasawneh (2024) study, which highlighted the effective role of educational robots in enhancing cognitive skills among students with hearing impairments. The study emphasized that educational robots create an interactive learning environment that transcends the limitations of traditional methods.

Additionally, these findings align with those of previous studies, which demonstrated that the use of intelligent robots significantly improves therapeutic outcomes for children with hearing impairments.

It is also important to note that educational robots provide a unique learning environment that specifically targets sensory and cognitive aspects in deaf children. This explains the statistically significant differences between the pre-test and post-test results. This

finding can be further interpreted in light of modern theories of interactive learning, which emphasize that multimodal interaction enhances the comprehension of complex spatial concepts.

This is further supported by Uluer & al (2023), whose study confirmed the effectiveness of using emotional assistant robots with children who have hearing impairments. This consistency in findings underscores that the educational robot intervention did not merely enhance cognitive abilities and improve spatial perception skills, but also extended its impact to emotional and interactive aspects of learning.

From a cognitive-spatial development perspective, the findings of this study align with those of Badrina (2014), which examined the relationship between the acquisition of spatial linguistic units and cognitive processes in deaf children. The educational robot functions as a bridge between abstract concepts and the concrete representation of spatial relationships.

These results also support the findings of Brainin, Shamir, and Eden (2022), which demonstrated that robot programming contributes to the enhancement of language and spatial abilities. Their study confirmed that interactive robot programming aids in the development of language and cognitive skills among children with learning difficulties.

Furthermore, the high effectiveness achieved in this study suggests that deaf children with cochlear implants may respond positively to robot-assisted learning, benefiting from the partial auditory perception provided by the implant. This facilitates the integration of auditory and visual cues, thereby reinforcing their learning experience.

In the context of digital transformation, the findings of this study align with those of Ammar (2021), which highlighted the positive impact of educational robots on academic achievement. Similarly, the study by Al-Akhtar and Al-Freih (2022) demonstrated that integrating educational robots within digital transformation strategies not only enhances academic performance or innovative skills in isolation but also provides a comprehensive educational solution that enriches the learning experience across various fields.

This suggests that the use of educational robots extends beyond mere technological advancements, evolving into a key tool for achieving inclusive education, particularly for learners facing educational challenges, such as deaf children.

Based on the foregoing, the findings confirm the effectiveness of using artificial intelligence technologies within the proposed intelligent robot in enhancing spatial prepositions among deaf children with cochlear implants. These results align with modern research trends in technological intervention for individuals with special needs.

The applied results further highlight the potential of employing this technology in the design of comprehensive training programs and the development of innovative assessment strategies. This opens promising prospects for the advancement of similar intervention programs in the educational and therapeutic fields for individuals with hearing impairments.

5. Conclusion

Spatial prepositions develop throughout the learning process, requiring children to undergo continuous training to perceive the position and direction of objects accurately. However, the concept of space remains particularly challenging for deaf children in general. Nevertheless, our study demonstrates that integrating modern technology and artificial intelligence can facilitate spatial understanding, as evidenced by the study's findings.

Recommendations

- It is essential to provide guidance and training for teachers and specialists on integrating artificial intelligence technologies and modern educational tools, such as intelligent robots, into curricula for children with hearing impairments.
- Current educational programs should be adapted to incorporate various artificial intelligence technologies for both typically developing children and those with hearing impairments.
- Further future research is necessary to explore the effectiveness of artificial intelligence applications in intervention programs addressing various developmental and learning disorders in children.

AI Statement

Artificial intelligence tools were used solely to assist with proofreading certain parts of the manuscript. They were also used as a supplementary aid in organizing and cross-checking bibliographic information and in translating certain terms. However, all references were independently verified by the authors using the original sources. AI tools were not used to generate research data, conduct statistical analyses, interpret the results, or formulate scientific claims.

Ethical Statement

This study was conducted as part of a doctoral dissertation project and received the necessary institutional permissions and ethical approvals prior to the commencement of data collection. All required authorizations were obtained from the relevant institutions and stakeholders. The rights, privacy, confidentiality, and anonymity of all participants were respected throughout the research process.

Funding Statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Authors' Contributions

Nouani, H.: Conceptualization, theoretical framework, and literature review.

Karboua, S.: Methodology, research design, statistical analysis, translation, manuscript preparation, and correspondence with the journal.

Benchabane, L.: Fieldwork, data collection, data analysis, and implementation of the practical component of the study.

All authors read and approved the final version of the manuscript.

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