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Article

Robotic assistants for the rehabilitation of communication disorders in children: A proposal based on MTO manufacturing for developing countries

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Abstract: Language is fundamental to human communication, allowing individuals to express and exchange ideas, thoughts, and emotions. In early childhood, some children experience communication disorders that impede their ability to articulate words correctly, posing significant challenges to their learning and development. This issue is exacerbated in developing countries, where limited resources and a lack of technological tools hinder access to effective speech therapy. Traditional speech therapy remains vital, but the latest technological advancements have introduced robotic assistants to enhance therapy for communication disorders. Despite their potential, these technologies are often inaccessible in developing regions due to high production costs and a lack of sustainable manufacturing models. For these reasons, this paper presents "FONA," a robotic assistant that employs rule-based expert systems to provide tactile, auditory, and visual stimuli. FONA supports children aged 3 to 6 in speech therapy by delivering exercises such as syllable production, word formation, and pictographic storytelling of various phonemes. Notably, FONA was successfully tested on children with cochlear implants, reducing the number of sessions required to produce isolated phonemes. The paper also introduces an innovative analysis of the Make To Order (MTO) manufacturing system for producing FONA in developing countries. This analysis explores two key perspectives: collaborative networks and entrepreneurship, offering a sustainable production model. In a pilot experiment, FONA significantly improved children's attention spans, increasing the period by 17 min. Furthermore, the economic analysis demonstrates that producing FONA through collaborative networks can significantly reduce costs, making it more accessible to institutions in developing countries. The findings suggest that the project is viable for a five-year period, providing a sustainable and effective solution for addressing communication disorders in children.

Keywords: speech-language therapy; robotic assistant; children; special educational needs; dyslalia; make to order; sustainable technology development

1. Introduction

Over time, communication disorders have affected millions of children worldwide. For example, in the United States there are 40 million cases, in the United Kingdom 1 million, in Australia 1.1 million, among others (Velásquez-Angamarca et al., 2019). On the other hand, in South American countries such as Chile in the period between 2010 and 2016, 6% of the total number of children with communication disorders increased. While in Ecuador there are still no comparative figures on the number of children with communication disorders (Robles-Bykbaev et al., 2018).

It should be noted that in Ecuador not all children and adolescents attend education, according to INEC statistics 28.4% do not do so due to lack of economic resources, where in most cases the students have presented speech difficulties including dyslalia (Instituto Nacional de Estadística y Censos, 2021). This disorder has a prevalence of 5% to 10% in children, making it one of the three most prevalent language disorders. Dyslalia appears at an early age, starting at three years of age, and if not treated in time, it can lead to poor academic performance, difficulties in transmitting ideas, thoughts, among others (Álvarez-Borrero and Zambrano-Ruiz, 2017). A speech and language expert will be in charge of diagnosing this type of disorder, where support will be provided to children through therapeutic exercises.

Information and communication technologies (ICT) are a tool for paradigmatic changes in the educational field, bringing with them differences between inclusion and exclusion. Where it is evident that they arise and influence as an alternative for improvement in rehabilitation and therapy processes in people with or without disabilities, which is why, if we do not use inclusive technologies in the classroom, it is possible that we are entering into exclusion (Flórez Buitrago et al., 2016). UNESCO determines that having an inclusive education considers reinforcing the process by which we reach all learners with and without disabilities. In addition, it is based on the fourth Sustainable Development Goal 4 (SDG), which indicates that inclusive education allows children to learn without discrimination. Therefore, it is essential to find methods that facilitate their learning style (Badilla-Quintana et al., 2020). Therefore, the integration of robots and technology in inclusive education makes it possible to generate spaces that enrich equal opportunities (Daniela and Lytras, 2019).

Nowadays, therapy by means of robots has had greater prominence, showing better results compared to traditional therapy. These robotic assistants provide help to the user in order to improve their levels of attention and motivation (Calderita et al., 2015).

In developing countries such as Ecuador, there are few technological tools that provide support in the intervention of children with communication disorders. This is due to several factors, such as the lack of economic resources, qualified personnel and technological devices that allow the development of new support tools. In addition, speech therapists are subjected to work overload, since they must perform several activities such as intervention, follow-up, planning, etc., thus affecting the quality of care they must provide to children (Robles-Bykbaev et al., 2018).

Meanwhile, micro-enterprises in Ecuador represent 90.78% of the businesses, small enterprises 7.22% and midsized enterprises 1.55%, focusing on commerce and service production activities (Alvarado-Choez et al., 2021, p. 19; Huilcapi MasacónMasacón et al., 2020). However, one of the reasons for the existence of a large number of entrepreneurships in developing countries is to generate alternative sources of income due to the lack of employment and job opportunities. The creation of these is based on satisfying the needs of the population, market conditions and access to economic resources (income and expenses), as well as the participation of collaborative networks that support the formation of businesses for entrepreneurs to carry out their initiatives and achieve benefits for both themselves and the community (Zamora-Boza, 2018). It is worth noting that according to the Global Entrepreneurship Monitor, 90% of entrepreneurships disappear after the third year (Valenzuela-Klagges et al., 2018), for not having sufficient demand, for not implementing innovation strategies and for not carrying out an adequate cost analysis, among others.

The European Graduate Institute mentions that entrepreneurship and innovation go hand in hand and have become more popular in recent times (Alvarado-Choez et al., 2021, p. 19). In addition, it is important to apply sustainability principles in this practice by considering social, environmental and economic factors (Bausys et al., 2019). Thus, when the manufacturing system is introduced, each factor enters into each of the product's life stages, starting with the design stage, manufacturing stage, use stage and ending at the post-use stage (Bi, 2011). The design and manufacturing stages refer to the price of production where raw materials, labor costs, energy costs, administration costs, indirect costs, packaging and transportation costs are included, while the last stages refer to maintenance costs. The commercialized products should be flexible to the needs of the population and maintenance costs should be reduced as long as their quality is guaranteed (Bausys et al., 2019).

Based on the above, this article develops the sustainability study of the mass production of a robotic assistant called FONA. This robot aims to meet the needs of children with communication disorders. Therefore, two different perspectives for the production of the robot are considered in this study: entrepreneurship and collaborative networking. The rest of the article is organized as follows. Section 2 reviews work related to the production of robotic assistants. Section 3 describes an analysis of the factors involved in the FONA robot production process. Section 4 presents the main results obtained with the analysis and experimentation plan. Finally, section 5 describes the conclusions.

2. Related work

This section describes some work involving sustainability for technology tools in inclusion. Serpa-Andrade et al. (2020) developed a sensor-equippedtriangular pen whose software is capable of collecting and analyzing children's handwriting data. This tool helps in the learning progress of children with and without disabilities. In addition, it is a low-cost device with a sustainability perspective, making it an accessible tool for children from low-income families.

Gupta et al. (2017) created the S-Pencil electronic device which consists of an accelerometer and a pressure sensor. It collects data in real time to monitor the child's writing activity. The prototype is low-cost and accessible to all children due to its size and shape.

Cufí et al. (2021) described a proposal for an educational underwater robot called EDUROV. Which has evolved with the aim of being sustainable, it also allows the remote operation of underwater vehicles from anywhere in the world. High school students and teachers through the results consider that the prototype is useful to introduce technical and scientific concepts as it is a low-cost tool whose materials are easy to obtain.

Hernández et al. (2021) created a humanoid robotic assistant, for its construction 3D printing and low-cost electronic elements were used, with the aim of lowering the price of the robot to make it accessible to society. It can be used in education, entertainment, therapies, social robotics systems, among other alternatives.

Jae-Hyun et al. (2020) developed a steel pipe head cutting robot to improve work safety, productivity and product quality. Through a comprehensive performance and economic efficiency analysis, they demonstrate that the use of the developed robot is sustainable and feasible, which will be commercially available in the future. Once the robot is applied in construction sites, it will be possible to prevent work accidents, improve productivity efficiency and reduce supplies costs.

In Alves-Oliveira et al. (2019) conducted a field study on an empathic autonomous robot for learning. In which they develop tests with groups of students to determine the degree of learning under two criteria: with empathic robot and without empathic robot for two months. The results indicated that learning was not as significant in the long term, concluding that the empathetic autonomous robot drives meaningful discussions on sustainability.

Sidiropoulos et al. (2021) presented a software with augmented reality in the business area. It was developed with a robot operating system that identifies the shortest destination between the employee and the production area in the industry and a mobile application that presents the route in the virtual environment of the destination. Finally, they conclude that the inclusion of AR is an interesting medium that favors the training of new employees as well as operational activities of experienced employees, generating a direct impact on sustainability indicators.

Estévez et al. (2021) developed a case study of a Zenbo robot for children with communication disorders. The therapy sessions with the social robot were individual, where they implemented qualitative methods. The objective is to obtain data on aspects of feasibility and usefulness; in this way they demonstrated that the robot increased the child’s level of motivation and there were improvements in vocalization, sentence structuring and sentence construction.

Yi-Zeng et al. (2020) designed and built two robotic assistants called Zenbo to improve the learning efficiency and motivation of teachers and high school students. The emotional robots interact with each other in the classroom by helping students solve problems and answering questions using a big data system. It also evaluates the user’s moods, the purpose of which is to demonstrate that these techniques and methods applied in the classroom by means of assistants are sustainable.

Borggraefe et al. (2010) conducted an investigation of sustainability of robot-assisted treadmill therapies for children and adolescents with central gait disorders. Through tests performed, they can conclude that the implementation of said therapy is sustainable for a period of six months onwards, where it was demonstrated that there are improvements in the patients.

Several research studies indicate that inclusion robots in education arouse learning motivation in students. In their paper Chun Hung et al. designed a robotic assistant to enhance learning motivation in English reading. Through this development they used a quasi-experimental design and motivational surveys for data collection. They showed that the progress of the students was progressive once they applied the robot-assisted instruction (Hung et al., 2013).

In Santana et al. (2007) developed a four-wheeled robot for use in urgent situations in remote locations. The authors in this study seek the sustainability of the robot in terms of economics, ecology, maintenance and re-engineering. They used low-cost and locally available components, intuitive design methods and simple sensors to build the robot. In addition, they use the Survival Kit architecture oriented to disposable robots. Finally, they conclude that by using these methods they made possible the sustainability of the robot.

Wang et al. (2009) developed a force sensor in the form of a pencil in order to find out the feasibility of signature verification for people with and without disabilities. The device has a small metal frame, force sensors, gyroscopes that are commercially available, the pencil is low cost and accessible due to the time it takes to manufacture the device.

In Valadão et al. (2016), a mobile robot named MARIA was created, featuring a special costume to enhance its friendliness. Designed to display multimedia content, MARIA aimed to effectively interact with children with Autism Spectrum Disorder (ASD). The robot contained a variety of images, videos, and other visual media to capture the attention and interest of children. During therapy sessions, a meter controlled and directed the robot’s movements. The results were promising, as four out of the five participating children improved their social skills.

Zheng et al. (2016) introduced a humanoid robot named RISTA, equipped with a camera, specifically designed to teach imitation skills. The robot demonstrates a gesture that children must imitate, and then evaluates the performed movement, providing real-time feedback. This feedback allows users to correct their actions immediately and improve their technique in the process. The results indicate that the robot enhances the attention of children with ASD more effectively than a human therapist.

Del Coco et al. (2018) presented a technological mechanism that integrates visual signals, such as face detection, gaze stimulation, and facial expression recognition, to analyze the behavior of children with ASD during their interaction with a humanoid robot. The sessions conducted with eight children with ASD achieved an accuracy of over 90%, demonstrating the potential of this tool to improve diagnosis and evaluation in ASD therapies.

Nunez et al. (2018) introduced paired robotic assistants named COLOLO, which help improve communication between children with ASD and therapists, focusing on turn-taking. The results suggest that COLOLO can be a useful tool for improving and quantifying turn-taking behavior in children with ASD.

In Feng et al. (2022), the authors present the programming of the NAO robot, based on music therapy to improve social skills in children with ASD. The system allows for playing instruments, reproducing recorded and personalized songs, and providing musical feedback. Through a study conducted with nine children with ASD, the majority completed tasks with 70% accuracy, highlighting it as a promising tool to support children with ASD.

Javed et al. (2019) describe a robot designed to help children with ASD overcome sensory difficulties through sensory stations that recreate everyday scenarios. Leveraging the interest of children with ASD in technology, the platform seeks to teach social responses and improve social, motor, and vocal skills. A preliminary study with 18 children, including 5 with ASD, evaluated the system’s effectiveness in improving social engagement and identified key design elements to enhance it.

With the aim of improving classroom behavior, Beaudoin et al. (2021) propose the use of a humanoid robot in conjunction with a haptic bracelet to help children with ASD manage their time more efficiently. However, it is important to note that the pilot study was conducted with only two participants.

In their research (Louie et al., 2021), they conducted a study evaluating the effectiveness of applying Applied Behavior Analysis (ABA) techniques through robots in an auditory comprehension intervention for children with ASD. The results showed that all participants improved in the taught skill, and one of them mastered it, highlighting the enjoyment and positive participation during the sessions.

Liu et al. (2021) designed an interactive cognitive training tool to improve color learning in autistic children, overcoming the limitations of the traditional approach. It uses technologies such as LED screens, voice recognition, and infrared positioning to create a more engaging and effective learning environment.

In their research (Boyle and Arnedillo-Sánchez, 2022), they developed an application for the development of reading and language skills, focused on helping children identify letters and associate sounds with images of common objects. The research adopted a collaborative design approach, working directly with children who have ASD.

In their article, the authors (Linden et al., 2023) create an application for a social robot to help improve speech in people with aphasia. The evaluation showed good results in terms of usefulness and ease of use, with most exercises completed without assistance.

In the article developed by Lekova et al. (2022), a social robotic assistant is proposed to treat speech and language disorders in four-year-old children. This system focuses on helping children to correctly pronounce farm animal names while being monitored by a therapist. On the other hand, Spitale et al. (2021) presents a social assistance robot that includes a tablet offering various activities for training and evaluation of language skills in children aged 2 to 12 years with language disorders. The results are preliminary as only one condition on the tablet was evaluated.

Lekova et al. (2021) proposes the use of the Pepper robot for children with hearing impairments, with the aim of developing spoken language through auditory and visual cues. Pepper uses auditory, visual, or combined approaches and offers personalized protocols to adapt to the child's individual needs and family routine. Interactions can include gestures, the robot's voice, human tutor assistance, serious games, or sign language on a tablet.

Finally, Polycarpou et al. (2016) investigates the use of the NAO robot to assess listening and speaking skills in students with hearing impairments who use cochlear implants and sign language. NAO, lacking a mouth, avoids lip reading, which could make the evaluation more accurate. Preliminary results indicate that NAO is effective for this task and suggest that social robots could improve assessment.

Table 1 below shows the comparison of the different technological tools in relation to population, estimated cost, approximate manufacturing time and sustainability analysis.

As we can see, several technological tools do not have a sustainability study, so we cannot verify that the tool is viable and sustainable over time. This is a critical factor, because if a proposal to support children with dyslalia or other disorders is not sustainable over time or cannot be mass-produced, it will not really reach the population that needs it so much.

Table 1. Comparison of most relevant technological tools considering the estimated production cost, manufacturing time, and sustainability analysis.

Tool	**Population**	**Estimated cost (USD)**	**Estimated manufacturing time (days)**	**Sustainability analysis**
Sensorized pens	Children with or without disabilities	$50.00	5	Yes
S-Pencil	Regular children	$280.00	6	No
Edurov	Regular children	$200.00	10	Yes
Humanoid robot	Children with physical disabilities	$350.00	8	No
Steel pipe head cutter robot	Industrial operators	$600.00	18	Yes
Empathic robot	Children with or without disabilities	$400.00	15	Yes
Robot Operating System (ROS)	Industrial operators	$300.00	21	No
EBA robot	Children with communication disorders	$900.00	60	No
Zenbo robots	High school students	$1500.00	50	No
Assistance robot	Children and adolescents with physical disabilities	$1200.00	60	Yes
RTA robotic assistant	Children with or without disabilities	$600.00	21	No
4-wheeled robot	Children with disabilities	$350.00	10	Yes
Sensorized pen stylus	Regular children	$160.00	5	No

Source: Own.

Brief comparative analysis of the proposal with existing works

Minoofam et al. (2022) describe an adaptive reinforcement learning tool for teaching students with dyslexia called RALF. This tool offers features such as letter and word generation, a customizable interface with adjustable writing speed and font color options, as well as interactive activities and educational games. Additionally, RALF provides pronunciation support and graphical assessments to monitor student progress. When implemented, this tool has been shown to improve both the attitudes and learning outcomes of elementary school students.

However, our proposed tool called FONA provides exercises such as phoneme, syllable, and word pronunciation to assist children with communication disorders, including dyslalia. After implementation, our assistant has shown significant results, such as improved attention during therapy sessions compared to traditional methods.

Takbiri et al. (2019) introduced an online platform designed to enhance student learning efficiency and performance through gamification techniques. The platform aims to engage and motivate children by creating an attractive environment where they can learn, experiment, and enjoy simultaneously. This is achieved by integrating gamification elements, mitigating negative effects on motivation, and promoting more effective learning. However, a potential drawback is that gamification elements may not be equally effective for all students, as individual learning styles and motivations vary. Poorly designed gamification elements could be distracting rather than facilitating learning.

In contrast, FONA offers a user-friendly application incorporating phonetic discrimination games. This enhancement provides positive reinforcement when children complete activities correctly, making the exercises more engaging, interactive, and motivating. However, negative reactions are triggered when children make mistakes, which could potentially demotivate them.

In a similar vein, Takbiri et al. (2023) proposed a web application that employs gamification elements to assess their impact on student learning. Their aim was to analyze how these elements influence user performance and engagement within an educational platform. The results indicated that over 82% of students perceived positive effects of gamification on their learning experience and performance. However, the study presents some limitations, such as a small sample size, which restricts the generalizability of the results.

Meanwhile, FONA, after conducting therapy sessions with a robotic assistant compared to traditional therapy sessions for two months with eight children, demonstrated an average increase of over 17 min in the children's attention span during a 40-minute therapy session (Velásquez-Angamarca et al., 2019).

Regarding resource creation, the work proposed by Bastanfard et al. (2010) aims to create a Persian audiovisual data corpus, named AVA II, focused on coarticulation and its impact on speech. This corpus is fundamental for research in areas such as audiovisual speech recognition (AVSR) and lip reading. Additionally, the goal is to optimize data collection through the use of more efficient phonemic combinations and to improve the corpus's utility for future applications.

In the same context, the FONA application includes a variety of exercises and activities with 27 phonemes, incorporating a speech recognition module (ASR) and utilizing an MVC (Model-View-Controller) architecture. One of the highlighted activities is lip stimulation, where a GIF is presented showing lip movements accompanied by the corresponding audio for each phoneme. The child must imitate what they see and hear, while the therapist supervises and evaluates the accuracy of the imitation. Furthermore, the application allows for the recording of this data for subsequent analysis (Tenesaca-Tenesaca et al., 2021).

Bastanfard et al. (2009) proposes a Persian viseme classification for speech development, essential for computer-assisted pronunciation training and lip-reading applications. Viseme classification varies across languages and is based on the effect of coarticulation. In the case of Persian, an image-based approach is used to group visemes, where a central frame is selected from multiple images for each phoneme. Additionally, a table is established that links visemes with phonemes, and different classification methods, both model-based and image-based, are applied.

Similarly, FONA offers activities designed for 27 simple and compound phonemes of the Spanish language. Among these activities, one is particularly focused on lip stimulation, where a GIF based on a sequence of images is presented. This GIF allows the child to interact dynamically with a robot, facilitating the practice and development of their oral skills (Tenesaca-Tenesaca et al., 2021).

To date, the evaluation of these activities has been conducted exclusively in children aged 3 to 6 years. This developmental stage is crucial, as it is when children require the most attention and support in speech development. Interaction with FONA during these early years can be fundamental to strengthening their language skills and ensuring adequate development of their communication abilities.

3. Background: Robotic assistant "FONA"

The difficulties that certain children have to pronounce correctly the sounds of language, are known as Dyslalia and is one of the most common problems in the expression of speech. Dyslalia in most cases is due to an abnormal functioning in the process of acquisition and development of language, motivated by some causes and in general terms has a favorable prognosis for recovery.

There are different types of dyslalia (developmental, organic, auditory and functional). Children with this problem present difficulties of omission, substitution, distortion or addition of phonemes when producing words. According to several studies, the phonemes with greater difficulty of pronunciation are (s−k−l−z−ch−d) and the syphons or double consonant syllables (Española, 1995).

Early attention in children with dyslalia is essential, as it will improve the articulation of each phoneme and thus obtain an adequate pronunciation of oral language, which will serve as a foundation for the acquisition of an adequate reading and writing process. In this sense, the intervention can be done through an indirect treatment aimed at improving all the functions involved in speech (breathing, relaxation, oral-facial motor skills, auditory discrimination, among others) and direct treatment that aims to teach the child the correct emission of each phoneme and consonant clusterand integrate it into their spontaneous speech production.

To work with children with dyslalia, a robotic assistant called FONA has been built, which has the following objectives: (i)Improve articulation/pronunciation of speech sounds. (ii) Contribute to the development of phonological awareness. (ii) To develop auditory discrimination and auditory memory skills. (iv) Improve the child's attention levels. (v) To motivate interest in learning. This covers essential aspects of both direct and indirect treatment of speech rehabilitation. In this regard, Pascual García points out that while the child is learning to articulate new phonemes, it is also necessary to discriminate and recognize them aurally (Española, 1995).

FONA, proposes the following activities: (i)Teaching of the articulatory point and mode of each phoneme and consonant cluster in isolation. (ii) Association of the phoneme with an onomatopoeic sound. (iii) Reproduction of the phoneme in combination with vowels. Production of the phoneme in direct syllable. (v) Production of monosyllabic, bisyllabic, trisyllabic and polysyllabic words containing the phoneme. (vi) Auditory discrimination of words containing the phoneme. (vii) Reproduction of a story elaborated with words containing the phoneme or a tongue twister. (ix) Production of short sentences with words containing the phonemes to be worked on.

The FONA robotic assistant was created with the purpose of providing children with new technological, creative and innovative tools that facilitate the production of speech in a playful, recreational and motivating way. By allowing the manipulation and exchange of information, this tool encourages curiosity and the spirit of inquiry in early childhood education children, allowing them to be the protagonists of their own learning. Marotias (2009) argues that nowadays, children have a natural connection with technological devices, which significantly influences their motivation and desire to learn. FONA was implemented in educational centers in the city of Cuenca.

3.1. The main elements and functionalities of FONA Robot

The robotic assistant was built with the aim of providing support with the activities mentioned above as well as increasing the children's attention span during the therapy sessions. Similarly, we pretend to take advantage of an effect reported in the literature when teachers include robots in educational processes: it draws children attention and motivates them to work even in repetitive exercises. As can be seen in **Figure 1**, the robot FONA implements several functionalities and services.

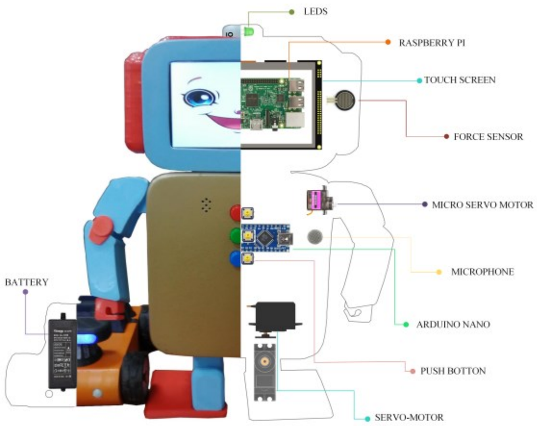

Figure 1. The FONA's structure: the left part depicts the external structure (printed in 3D) whereas the right part shows the internal electronic components (Source:own).

The most relevant features and functionalities of the robot are described below. The robot has 6 degrees of freedom (can move arms and walk), weights six pounds, has a touch screen of 5 inches, has three push buttons (chest) to incorporate any kinesthetic stimulus and two resistive sensors (head) that can trigger any script written in Python or C, and can play sounds through a Bluetooth speakers. Similarly, the robot includes a microphone and Automatic Speech Recognition (ASR) offline system, to help children with the pronunciation of any phoneme of Spanish language. The electronic and 3D components used to develop the robot are the following:

- A Raspberry PI 3 model B + microcomputer that is the central robot controller. This device contains an application developed in Python that presents several activities related to 17 phonemes (Spanish): working with pictograms and stories, associating pictograms and phonemes, repeating words, etc. Likewise, the application implements a module based on speech recognition to ask the child to pronounce words;
- A set of 6 servomotors (for arms, knees, and ankles);
- An Arduino Nano card to control the servomotors;
- A 5 inches touch screen.

Below we present a brief overview of the type of feedback that provides the robot to children from the perspective of motor learning theory. This analysis is essential, due to the close connection between intervention on children with dyslalia and the feedback that the therapist or robot provides them regarding after executing an exercise or command.

3.2. Feedback provided by the Robot: A perspective from motor learning theory

In Motor Learning Theory, two kinds of feedback are proposed (Sharma et al., 2016; Zwicker and Harris, 2009):

- Knowledge of Results (KR)—this is simply a comment or prompt—it could be verbal feedback such as "good" or "that's it" or "wonderful" · · · or it could be a light coming on a robot or a pleasant sound of some type.
- Knowledge of Performance (KP)—this is explicit information specific to the attempt - for example, "you remembered to touch your tongue behind your teeth for your /L/ sound" or "great job of putting the /t/ on the end of 'bat'".

In this line, research tells Us that each type has a greater effect at different times in the learning process. A lot depends on stimulability and the learner's awareness of their own speech. Currently, our robot uses feedback based on KR. However, we are developing a new interaction interface for the robot (on the base of the speech recognition module) to provide input feedback on KP.

3.3. Expert system

In Ecuador there is a lack of estimates about the real number of children that present Dyslalia and other related disorders of speech and language. For this reason, we have developed an expert system aimed at recommending exercises for the treatment of specific conditions related to Dyslalia.

The expert system allows establishing relations between the children profile and a set of exercises that must carried out by a therapist with the support of the robot FONA. Below we describe the main logical structures (through simple equations) that allow us to model the most relevant elements required in CLIPS (the tool used to build the expert system): templates, rules, and functions.

The first structure represents the child's profile (CP) through the following attributes: age (a), initial speech language screening (a vector with information of which phonemes can produce the child, $\overrightarrow{Ph}$), diagnosis (the type of Dyslalia that presents the child d), and gender (g) (Equation (1)):

$$CP = \{a, \overrightarrow{Ph}, d, g\} \tag{1}$$

The $T\vec{o}D$ structure represents the four types of dyslalias that exist (evolutionary, functional, auditory and organic), whereas $S\vec{y}m$ is a vector that refers to type of error committed during the pronunciation (omission, substitution, distortion, and insertions) (Mozo Rojo, 2017). The $\overrightarrow{AP}$ represents a vector of phonemes that could be affected in the child's utterances production. The $\overrightarrow{EX}$ is the set of exercises that are provided in the robot's interface (Equation (2)):

$$
\begin{gathered}
T\vec{o}D = \{ev, fu, au, or\} \\
S\vec{y}m = \{om, su, di, in\} \\
\overrightarrow{AP} = \{p_1 = /r/, p_2 = /s/, p_3 = /l/, \dots \dots p_{20}\} \\
\overrightarrow{EX} = \{e_1, e_2, \dots \dots \dots \dots, e_{50}\}
\end{gathered} \tag{2}
$$

Finally, our expert system implements around 30 rules to determine the following aspects: 1) if a given diagnosis is coherent, according to a given symptom and type of Dyslalia, and 2) which exercises should be carried out with a child according to the phonemes in those he/she present difficulties. Each group of rules generates facts to create an intervention plan progressively. It is important to mention that the analysis is done concerning $i-th$ child (Equation (3)):

$$
\begin{gathered}
(1) NewFact(S\vec{y}m_i\ is\ ok) \leftarrow \\
if\ S\vec{y}m_i \exists\ in\ T\vec{o}D\ (\overrightarrow{CP_i}) \\
(2) NewFact(\overrightarrow{CP_i}, \overrightarrow{AP_i}, \overrightarrow{ex} \subset \overrightarrow{EX}) \leftarrow \\
if\ \overrightarrow{AP_i} \exists\ in\ \overrightarrow{AP}(\overrightarrow{CP_i})
\end{gathered} \tag{3}
$$

3.4. Pilot experiment

On the other hand, a pilot experiment was conducted with two groups of children with communication disorders during a period of two months (with each group). The first group consisted of two children with hearing loss with cochlear implant (**Figure 2**) whereas in the second were included 8 children that present Dyslalia (without disabilities).

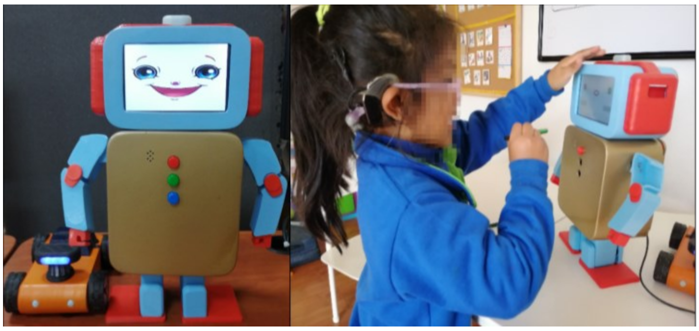

Figure 2. The FONA robot and its structure (left side). A girl with a cochlear implant interacting with the robot during a therapy session (right side) (Source: own).

The two children with cochlear implant have the following characteristics (one girl and one boy):

- Age: 5 years old;
- Diagnosis: moderate language delay due to hearing impairment;
- Language development: the two children have the same language development level according to the ELCE test (Comprehensive and Expressive Language Exploration test) (López Gines et al., 2014).

The Spanish Comprehensive and Expressive Language Evaluation (ELCE) was employed. This assessment is a comprehensive battery of tests designed to evaluate the language skills of children aged two years and six months to nine years. It provides both qualitative and quantitative data, including standardized scores for comprehension subtests, which allow for the identification of children who may require speech-language therapy and the development of targeted intervention plans (López Gines et al., 2014). This evaluation tool was administered both before and after the robotic therapy interventions. This pre-post design enabled a clear determination of the impact of using or not using the robotic assistant as a therapeutic support tool.

As it can be seen in **Table 2**, the child that worked with the robot was able to learn the isolated phone /r/ at second therapy session, whereas the other child reaches this goal at third therapy session.

Table 2. Number of sessions required by children to learn the isolated/r/phoneme and words with the same phoneme at the beginning, middle and end of certain words.

	Robot assisted therapy	**Traditional therapy**
	Session	**Session**
Spanish phoneme/word	Isolated phoneme production	
/r/ isolated	2nd	3rd
	Production of words in initial position	
ratón (mice)	3rd	5th
raqueta (racket)	N/A	N/A
rama (tree branch)	4th	5th
reloj (watch)	3rd	5th
resbaladera (slide)	4th	N/A
red (net)	4th	5th
río (river)	4th	5th
rompecabezas (puzzle)	3rd	N/A
rosa (rose flower)	N/A	N/A
rueda (wheel)	N/A	N/A
	Production of words in middle position	
pera (pear)	1st	N/A
torero (bullfighter)	N/A	N/A
mariposa (butterfly)	2nd	N/A
toro (bull)	3rd	N/A
números (numbers)	N/A	N/A
Perú	N/A	N/A
	Production of words in final position	
caminar (walk)	4th	N/A
tambor (drum)	5th	N/A

(Velásquez-Angamarca, 2019).

Similarly, the first child that worked with the robot had learned 7 from a total of 10 words with phoneme /r/ in initial position. The mean number of sessions was 2.5.

On the other hand, the second child that received traditional therapy had learn 5 words with a mean number of sessions of 5. For the goal "production of words with phone /r/ in middle position", the first child learned 3 words from a total of 6, with a mean of 2 sessions. However, the second child was not able to learn any word for this goal. Finally, for the last task "production of words with phone /r/ in final position" the first child learned the two words at sessions fourth and fifth, respectively (mean of 4.5). Nevertheless, the second child was not able to learn any word.

The second group of children have the following characteristics:

- Eight children present functional Dyslalia is some phonemes, and the other two in all phonemes;
- The children's age is between 4 and 5 years;
- The center where they receive therapy is the Municipal Child Development Center of the city of Cuenca—Ecuador (Centro de Desarrollo Infantil Municipal de la Ciudad de Cuenca).

In the same line, this group of children without disabilities was organized in two subgroups of five members (three girls and two boys) and the following structure: one child with difficulties in all phonemes and four children randomly selected from the group of six children with difficulties in some phonemes.

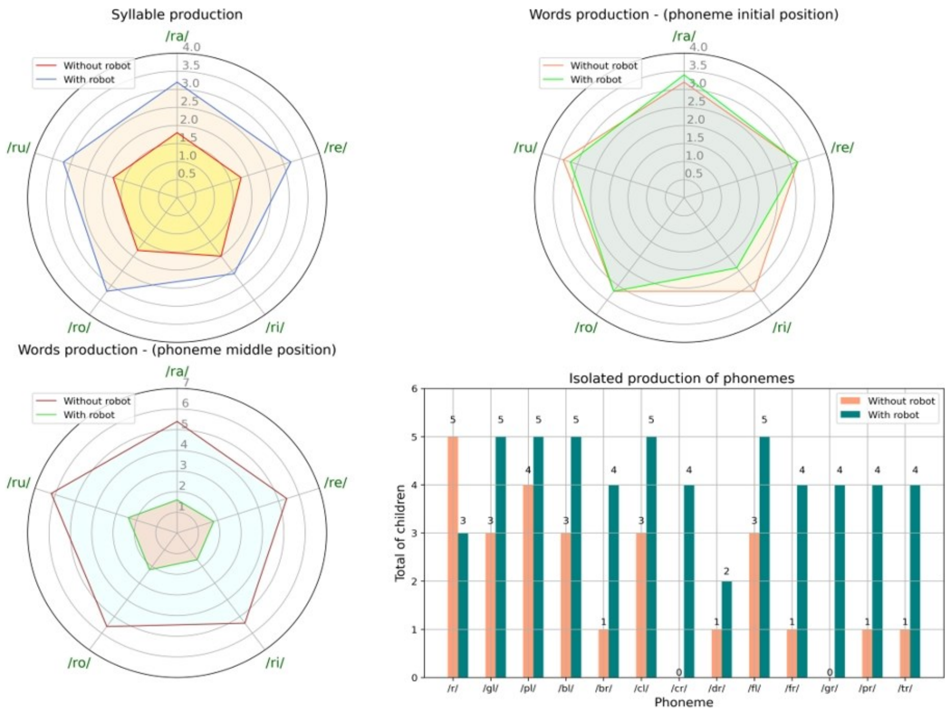

Figure 3. Progress in the pronunciation of traditional therapy phonemes compared to robot-assisted therapy (Source: own).

As can be seen in **Figure 3**, the subgroup of children that worked with the robot's can produce more syllables with Spanish phonemes /ra/, /re/, /ri/, /ro/ and /ru/ (upper left radial graph). On the other hand, for the production of words with the phonemes mentioned above in initial position, the results between the two subgroups are similar, having a slight advantage for the traditional therapy subgroup for the phoneme /ri/ (upper right radial graph). Conversely, the production of words in middle position, considered a harder task, shows that the subgroup that worked with robot support has better results in all phonemes (bottom left radial graph). For the last task, we can see that the firs subgroup has better results in the production of 12 phonemes from a total of 13 (bottom right bar plot).

Finally, it is essential to note when the therapists include the robot FONA in therapy sessions, the average children's attention span increases in more than 17 min (for a therapy session consisting of 40 min). It could be noticed that the motivation and attention levels of the children increased in an average of 17 min compared to the traditional therapy. In addition, the learning of phonemes was much faster.

4. Analysis of the factors involved in the FONA robot production process

This section describes the process that is carried out for the production of the FONA robotic assistant, having factors of high relevance within the context of sustainability, in order to know if the production process is viable and accessible. For which an analysis of the production planning, supply chain, supply and demand of the robotic assistant is performed.

Then, in order to know the feasibility of its massification, it is necessary to consider the different costs involved in production. which uses factors such as: machinery, materials, labor, inputs, technology, among others, in order to transform raw materials into finished products that are later marketed generating profit margins. The need has been seen to compare these factors from two perspectives such as entrepreneurship and collaborative networks.

4.1. Production planning

Initially it was planned that the production of parts for the FONA robot would be by means of 3D printers. Analyzing the capacity of the plant, it was noticed that implementing aluminum molds and 3D printers in the production increases it by 10%. Having as advantages that it will increase the quality of the finishing of the parts and will generate less waste. In addition, it can be indicated that in terms of production it was decided to use a make to order (MTO) manufacturing system, i.e., once the order is placed, the manufacturing process of the product begins. The capacity of the plant per enterprise with printers and molds is 10 robots per month, using 4 3D printers, which will be working 24 h a day, 4 molds and two operators who will be working 5 days a week for 8 h. While for collaborative networks the capacity was doubled using the same working conditions as in the case of entrepreneurship with the difference that there are 4 operators, 8 printers and 8 molds (see **Figure 4**).

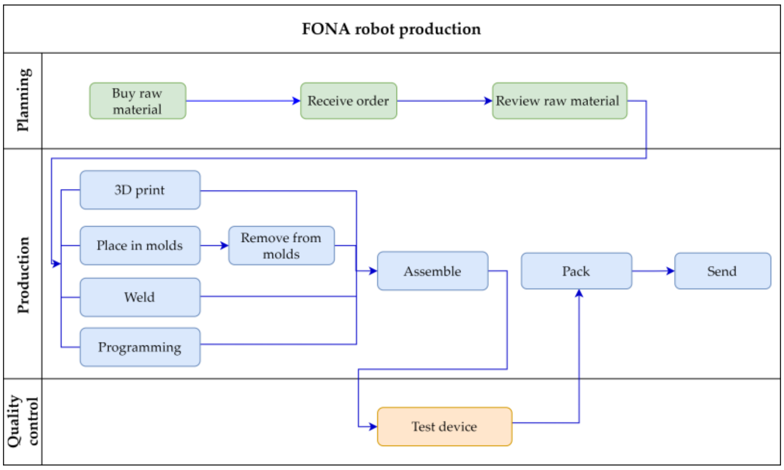

Figure 4. Diagram of plant processes by entrepreneurship and by collaboration networks (Source: own).

To determine the location of the project, a prioritization matrix was used to compare the industrial zone and the residential zone. This was evaluated using a rating criterion from one to ten, with one being the lowest score and ten being the highest. It was concluded that the best location alternative is the residential zone, due to relevant factors such as: available labor, proximity to the market and costs of basic services, thereby obtaining 63% of savings. By means of a scheme as shown in **Figure 4**, the possible scenarios to be considered within production are analyzed, such as the evaluation of suppliers and raw material purchases, in order to determine the best possible feasibility for production to be sustainable and accessible to demand.

Within the selection of raw material suppliers for the production of the robotic assistant, two possibilities were compared: one with a national supplier and the other with an international one. In addition, it was analyzed to buy in large and small quantities each one of the products; obtaining that the best purchase decision is to acquire the materials from international suppliers and in large quantities. In this way a 47% saving is obtained, however, to reach this saving it is necessary to make a high investment, because it is more convenient to buy in large quantities, since the fixed costs are divided for several supplies. Another important factor to highlight is that the production of the FONA robot was proposed with the support of collaboration networks, applying the same conditions as in other entrepreneurships. With this, entity would support the costs of machinery, tools, labor, basic service costs, software and especially with the facilities in order to have a lower cost and be accessible to the market. Analyzing the two perspectives, it was concluded that the best purchasing option for each enterprise is to acquire inputs from domestic suppliers in low quantities. This is due to the fact that the entrepreneurs do not have a high level of capital, which is cushioned in raw materials; otherwise, this budget would be used for machinery, tools, accessories, computer software, etc. On the other hand, through collaboration networks we can count on all the implements for the production of the robot, we can acquire raw material that represents our only investment, that is to say, it is convenient to buy wholesale from international suppliers (see **Figure 5**).

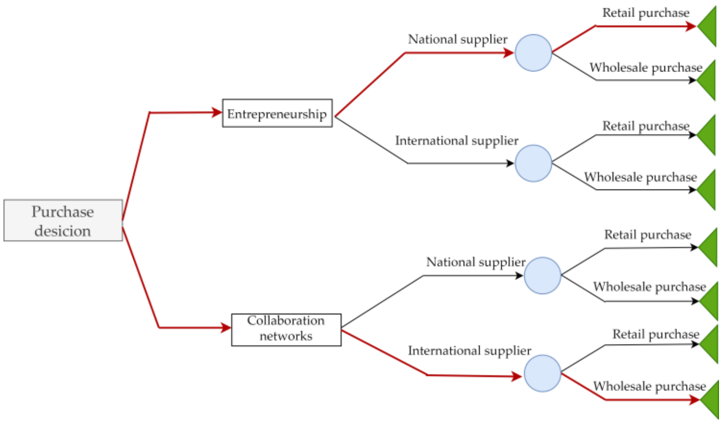

Figure 5. Schematic diagram for the purchase decision (Source: own).

4.2. Economic analysis

Table 3. Summary of production costs.

Production costs			
Entrepreneurship		**Collaborative networks**	
Fixed costs (USD)			
1) Workforce			
2 employees	$ 900.00	2 employees	$ 900.00
2) Utilities			
Water, electricity, telephone, internet	$ 38.09	Water, electricity, internet	$ —-
3) Machine maintenance			
Maintenance	$ 20.00	Maintenance	$ —-
4) Rent			
Rent	$ 100.00	Rent	$ —-
Variable costs			
1) Raw materials			
Supplies	$ 3191.20	Supplies	$ 1362.19
2) Indirect Costs			
Components	$ 17.20	Components	$ 3.48
3) Reagents for mold manufacturing			
Reagents	$ 280.05	Reagents	$ 251.82
4) Utilities			
Water and electricity	$ 33.98	Water and electricity	$ —-
5) Containers			
Boxes and plastic	$ 20.00	Boxes and plastic	$ 20.00

(Source: own).

A cost/benefit analysis measures the relationship between the cost per unit produced of a good or service and the profit obtained from its sale. In order to cost the FONA robot, three elements were considered: direct material, direct labor and indirect manufacturing costs. Cash flow was also considered, which is key in cost and profitability studies. The cash flow analysis helps us to visualize the usefulness of cash movements and the timing of these movements, not only for the entrepreneurship, but also for the partial production lines.

Table 3 summarizes the production costs, as well as the components required for the development of a robotic assistant with a production cost of $483.05. This value drops by 55% to $266.44, if the robot is built through collaborative networks.

When we face the challenge of making new investments, it is essential to know in advance the possibilities of success, profitability, the benefits it will bring and the viability of the entrepreneurship. The NPV and IRR, (Net Present Value and Internal Rate of Return) respectively, are two financial indicators that allow us to safely analyze the investment in the entrepreneurship.

4.3. Demand analysis

To determine the demand, a market study was conducted to find out the number of people who wish to purchase the robotic assistant offered. To carry out this process, a survey was developed containing 15 questions on a likert scale, with 1 being the lowest value and 5 the highest. Accordingly, the survey was validated with a sample of 25 people, in this case parents. By means of an analysis in the R studio software, a Cronbach's Alpha test of 0.92 was obtained, a value that is within the confidence limits. Thus, it was concluded that there is a correlation between the items, i.e., the survey is reliable.

According to data from the Ministry of Education (MINEDUC) for the year 2020–2021 there are about 475,670 children attending education between 3 and 6 years old in Ecuador. The National Institute on Deafness and Other Communication Disorders (NIH) argues that communication disorders affect 8% of children attending kindergartens (National Institute on Deafness and Other Communication Disorders, 2021).

Under this context, certain exclusion criteria are used, such as:

1) Parents with children attending schools located in zone 1,2,3,4,5,7,8,9.
2) Parents with children attending schools located in the provinces of Cañar and Morona Santiago.
3) Parents with children attending schools outside the city of Cuenca.
4) Parents with children living in rural areas.
5) Parents with children attending public, public/private schools.
6) Parents with children who do not have any communication disorder.

Table 4 shows the number of Ecuadorian children between 3 and 6 years of age distributed in the 24 provinces using the fourth and fifth exclusion criteria. With this we can say that there are about 57,603 regular children and 4608 children with communication disorders.

Table 4. Number of children aged 3–6 years in Ecuador with communication disorders and stratified sampling.

Province	Number of children 3–6 years old	Number of children with communication disorders (8%)	Stratified sample
Azuay	1594	128	10
Bolívar	23	2	0
Cañar	224	18	1
Carchi	353	28	2
Chimborazo	1301	104	8
Cotopaxi	577	46	4
El Oro	1386	111	9
Esmeraldas	745	60	5
Galápagos	0	0	0
Guayas	30,664	2453	189
Imbabura	770	62	5
Loja	1448	116	9
Los Ríos	1676	134	10
Manabí	3951	316	24
M. Santiago	46	4	0
Napo	70	6	0
Orellana	56	4	0
Pastaza	48	4	0
Pichincha	9220	738	57
Santa Elena	953	76	6
S.D. de los Tsáchilas	696	56	4
Sucumbíos	77	6	0
Tungurahua	1688	135	10
Zamora Chinchipe	37	3	0
Total number of children	57,603	4608	355

(Source: own).

Once the population is defined, the sample size is calculated using Equation 4, taking into account that the population is finite:

$$n = \frac{N \times Z_{\propto}^2 \times p \times q}{e^2 \times N - 1 + Z_{\propto}^2 \times p \times q} \quad (4)$$

where:

- n is the sample zise;
- N is the total population;
- Z represents the confidence level (in this case 95%);
- p is the expected proportion (in this case 50%);
- q is 1—p (in this case 50%);
- e is the maximum estimation error (in this case 5%)

With Equation 4, a sample size of 355 people is obtained, based on which a stratified random sampling is carried out to determine the number of people to be surveyed in each province, the results are shown in **Table 4**. In view of the above, due to lack of time and economic resources, the exclusion criteria described above are included in the study of the demand, in order to minimize the size of the population and with a convenience sampling. **Table 5** shows the number of children with communication disorders in Cuenca distributed in the different parishes of the city.

Thus, by applying Equation 4 and considering the same conditions, we obtain a sample size of 60 people that will represent the total demand at the level of the city of Cuenca. With this, we proceed to survey the parents, since they will be the possible buyers of the robotic assistant.

Table 5. Total population of children from 3 to 6 years old with communication disorder.

Parish	**Number of children 3–6 years old**	**Number of children with communication disorders (8%)**
Bellavista	32	3
Cañaribamba	92	7
El Batán	25	2
El Vecino	30	2
Hermano Miguel	9	1
Huayna Cápac	181	14
Monay	44	4
San Blas	55	4
San Sebastián	109	9
Sucre	137	11
Totoracocha	32	3
Yanuncay	146	12
Total number of children	**892**	**71**

(Source: own).

5. Results

For the experimentation process, 60 parents participated, of which 50 are women and 10 are men, with ages ranging from 22 to 50 years old (mean of 32.66 and StdDev of 6.02). **Figure 6** shows that the survey participants “strongly agree” and “agree” that the robotic assistant is a useful tool for their child, representing 45% in both cases (Q3). Likewise, parents think that the cost is “accessible” with 56.7% (Q2). Regarding the likelihood of purchasing the assistant, 41.6% of people would be willing to invest in the acquisition of the robot (Q4). Also, 43.3% agree and 16.7% “totally agree” that their child’s teaching-learning process should be through the robotic assistant (Q5). Regarding the 20% discount for the purchase of a second robotic assistant the respondents “totally agree” with 41.7%, while 33.3% “agree” (Q1). These ratings are highly positive regarding the cost and purchase characteristics of the robotic assistant.

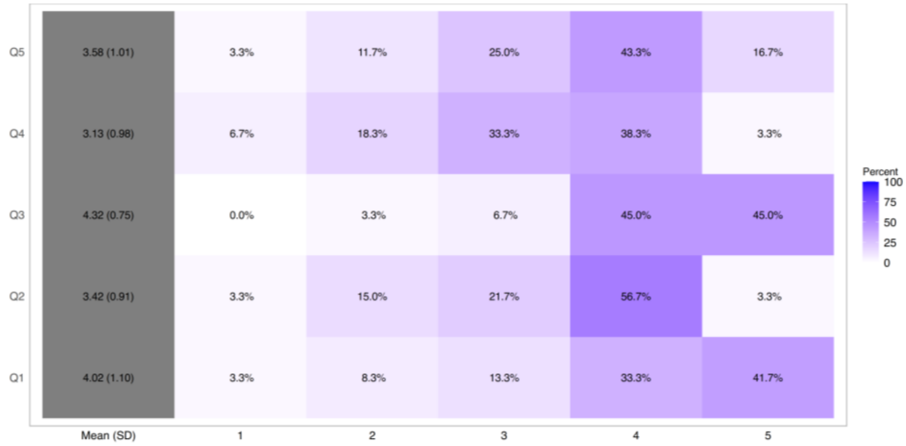

Figure 6. Ratings made by respondents regarding the cost of production of the FONA robotic assistant (Source: own).

Once the demand study was completed, the break-even point for each of the scenarios was analyzed. **Figure 7** shows that the break-even point for collaboration networks is 4.9, i.e., with this number of robot sales, all fixed costs will be covered and there will be no loss or profit. However, it should be noted that it would not be possible to sell 4.9 robots, but 5 units would have to be sold.

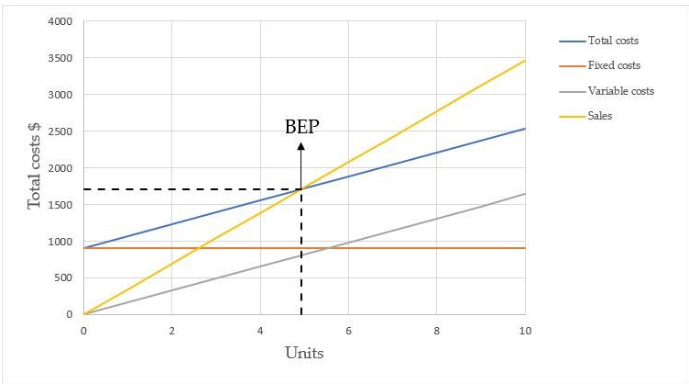

Figure 7. Break-even point for collaboration networks (Source: own).

In the case of the enterprise, the break-even point is 3.9 as shown in **Figure 8**, as mentioned above, only whole robot units can be sold, i.e., in this case 4 units must be sold to cover the fixed costs. With the survey data we can say that 41% of the people will possibly be able to buy the robot produced through collaborative networks and by entrepreneurship 20% of the people. With these results when analyzing the cash flow over a period of 5 years and considering each of the break-even points, it is observed that it is not even possible to meet the objective of selling the minimum units of robots to cover the fixed costs, due to the low demand in the city of Cuenca. This indicates that it is neither profitable nor sustainable over time in both scenarios. That is why it was decided to expand the market and thus expand the demand. We also saw the need to target children between the ages of 3 and 6 years old and that their parents are willing to buy a robotic assistant that helps and facilitates the learning of phonemes at a national level.

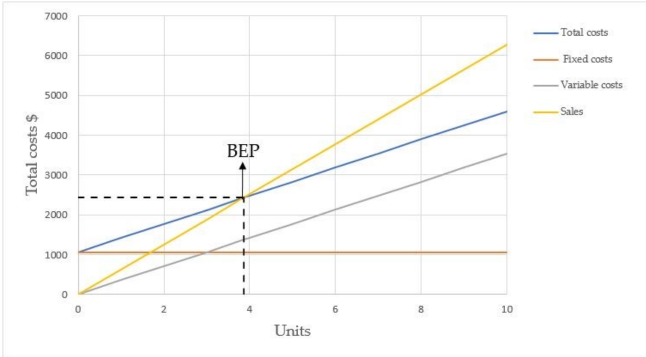

Figure 8. Break-even point per entrepreneurship (Source: own).

In the first four years of production of the FONA robot, the retail price is maintained, because the product does not exist in the market, therefore, a certain perception must be created in the consumer about the value of the robot. That is why from the fifth year onwards the retail cost rises by 5% both in the entrepreneurship and in collaborative networks, due to the fact that every year the cost of raw materials, labor and tools for production increases or fluctuates.

Figure 9 shows that sales through collaborative networks are higher because the retail price for this scenario is more accessible than for entrepreneurship. Therefore, the demand and probability of purchase is higher, which led to the decision to double the production capacity in collaborative networks.

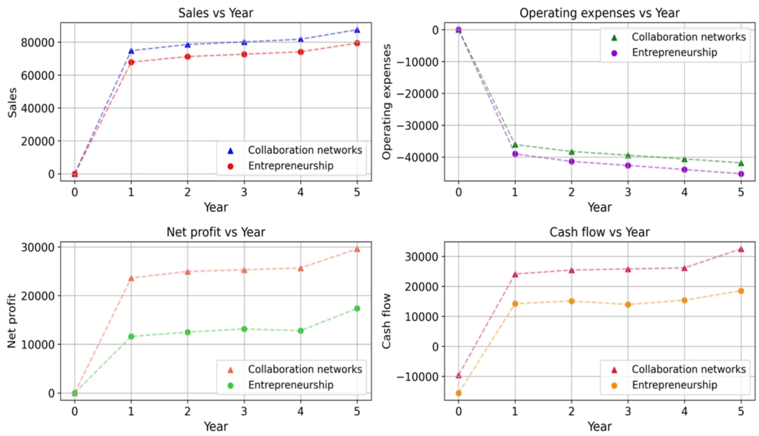

Figure 9. Flow from the perspective of entrepreneurship vs. collaborative networks. (Source: own).

Regarding expenses, it is indicated that they increase gradually each year, due to the inflation that can occur over time, either for raw materials, labor, transportation, among others, see **Figure 9**. In the net profit, it is observed that if the robots are made through collaborative networks, the net profit is higher than for entrepreneurship over the 5 years. This is due to the fact that by having an affordable price, more robots will be sold, thus generating more earnings and therefore more net profit.

The last part of **Figure 9** shows the cash flow, where it can be seen that the initial investment to start producing the Fona robot is much higher in the case of the entrepreneurship where the following are considered: machinery, computer equipment, molds, tools, accessories, computer equipment and working capital amounting to 40838.25 USD. While for collaborative networks, the initial investment takes into account: molds and working capital amounting to 9547.48 USD. On the other hand, it is also observed that after the first year in both scenarios liquidity is good, however, for collaboration networks there is greater liquidity. In terms of feasibility, it can be indicated that it is viable to invest in this project since analyzing the IRR we obtain a result of: 90.54% for entrepreneurship and 256.50% for collaborative networks, which indicates that the internal rate of return in both scenarios is very good. **Table 6** shows the summary of the two financial indicators in the different scenarios.

Table 6. Summary of IRR and NPV.

	Entrepreneurship	**Collaboration network**
NPV (USD)	$ 40,838.50	$ 88,159.60
IRR (%)	90.54	256.5

(Source: own).

6. Conclusion

It can be indicated that investing in the production of the robotic assistant FONA for entrepreneurship is feasible and viable, because the minimum IRR required for an investment to be profitable is 11%, obtaining an IRR of 90.54% for entrepreneurship and an IRR of 256.5% for collaborative networks. This value also indicates that, if you want to make a loan that usually the interest rate is 16% depending on the bank, it is feasible and also a profit would also be obtained in both scenarios.

In the scenario of collaborative networks it is observed that the investment is small compared to that of the entrepreneurship, due to the fact that the entity gives great support and in this way it is also observed that the IRR is quite high. When analyzing the two financial indicators, between the proposed scenarios, it is indicated that there is a higher internal rate of return and net present value, when we work with collaborative networks, since within the cash flow values are suppressed.

With the break-even point, it can be observed that the entrepreneurship needs to sell fewer robot units (4 units) to cover its fixed costs, while for collaborative networks it needs to sell 5 units, this is because the contribution margin contributed by the collaborative networks is smaller, so it needs to sell more to be able to cover the fixed costs.

In conclusion, the best way to produce the FONA robot is through collaborative networks not only because of the profit it generates but also because its cost is more accessible to the demand. In the same way, the robotic assistant would be a great contribution for children who present this communication disorder and also for children who do not present it, since with the different functionalities it has, it is a valid tool to support both the patient and the experts in the area; who look for different ways to draw attention and promote the practice of language exercises. Under this context it is important to state that the robotic assistant can also be acquired by natural persons who use it as a way to practice different exercises related to communication, at the same time that it can reinforce two important factors such as memory and concentration.

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