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metroSonus. An Inclusive Alternative for the Training and Direction of Visually Impaired Musicians Juanita Reina Zambrano; Diego Felipe Gaitán Lozano

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Abstract: metroSonus is the result of a study that proposed the development of a technological tool promoting the inclusion of the visually impaired in music training places, either as students, ensemble musicians, teachers, or conductors. This pedagogical tool transmits the orchestra conductor's pulse/beat to networked mobile devices to support the teaching–learning processes, as well as music interpretation. From the qualitative approach, the methodological orientation of this project is based on the praxeological research proposal developed by UNIMINUTO, which focuses on the reflection on practice by dividing the research process into four stages: observation, judgment, action, and creative feedback. This project poses new challenges and training requirements in the various areas that were explored for the development of metroSonus, as well as in the field of inclusive education and in areas such as computer viewing, machine learning, and artificial intelligence that are necessary for the continuation of this project.
Keywords: music; inclusion; blindness; visual impairment; technology; web application.

ES metroSonus. Una alternativa incluyente para la formación y la dirección de músicos con discapacidad visual.

Resumen: MetroSonus surge como resultado de una investigación que tiene como propósito la creación de una propuesta para el desarrollo de una herramienta tecnológica que propende por la inclusión de personas con discapacidad visual en los espacios de formación musical, ya sea como aprendiz, como músico parte de un ensamble o como orientador o director. Esta herramienta pedagógica transmite el pulso del director de orquesta a dispositivos móviles en red, con el fin de apoyar los procesos de enseñanza aprendizaje, así como de interpretación de la música.
La orientación metodológica de este proyecto se encuentra apoyada, desde el enfoque cualitativo, en la propuesta de Investigación Praxeológica desarrollada por UNIMINUTO, que tiene como eje la reflexión sobre la práctica y a la vez delimita el proceso investigativo en cuatro momentos: Ver, Juzgar, Actuar, y Devolución creativa.
Este proyecto de investigación plantea nuevos desafíos y exigencias de formación en las diversas áreas, que fueron exploradas para el desarrollo de *metroSonus*, así como también en el campo de la educación inclusiva y en aquellas que se hacen necesarias para dar continuidad a este proyecto, como es el caso del computer visión, el machine learning y la inteligencia artificial.
Palabras clave: música; inclusión; ceguera; discapacidad visual; tecnología; aplicación web

Overview: 1. Introduction. 2. Design and Method. 3. Field Work and Data Analysis. 4. Results. 5. Discussion and Conclusions. 6. References.

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1. Introduction

Education, being an axis for the transformation of cultures and societies, poses great challenges that must be faced by educational systems. Due to changes over the last century to strengthen educational proposals of human and social aspects, to develop solutions for a more democratic, inclusive, and plural society. The objective is to understand and address the causes and consequences of emerging exclusions at a cultural and systemic level, experienced by subjects due to degree of difficulty or the impossibility of accessing education.

The notion of "education for all" refers directly to the ideation and implementation of changes that go beyond perspectives focused on normativity, policies, or deficits. This is in the interest of strengthening pedagogical processes to consolidate inclusive cultures that promote the recognition of others based on epistemic, fair, equitable, and horizontal conception. Furthermore, this implies the need to strengthen practices promoting the development of inclusive processes, under conditions of equal opportunities in terms of resources, materials, and strategies to ensure full participation of all subjects and avoid exclusion, regardless of gender, economic or social status, ethnic or racial origin, geographic location, special learning needs, age, religion, achievements, and/or abilities (UNESCO, 2008). Thus, educational inclusion leads to transformation in the ways of feeling, acting, and thinking, especially how people conceive, recognize, and identify themselves within social and cultural groups.

Within this general context, the research project called *metroSonus* aimed to create a proposal for developing a technological tool promoting the inclusion of the visually impaired in music training spaces to facilitate not only their performance as students or ensemble musicians, but also as teachers or conductors. This article shows the results achieved after implementing the device, as well as the conclusions drawn from the development of this research process.

1.1. Studies on Disability in Education

There are various approaches to analyzing the theoretical concept of disability within the framework of different perspectives, adopted by several fields or disciplines of study. These views demonstrate how complex and controversial it is to reach a consensus on this issue. Advances in understanding this concept from mystical, religious, and medical notions to the current social, cultural, and anthropological perspectives, which allow us to develop broad approaches decentered from the subject's biological deficit, to focus on the complexity of social and cultural phenomena that intersect when establishing notions about disability.

The concept of disability in this research is based on the Disability Studies in Education (DSE) as a theoretical framework for its conceptualization from educational perspectives. Baglieri et al. (2011) explains that this view allows us to place disability through human expectations and interactions in a social context and indicates that disability is variable and can change over time. Furthermore, he adds that social interpretations of disability are influenced by racial constructs and intersections of race and ability, which marginalize many students This perspective, identifies disability as a socially and politically constructed response to actual or perceived differences. Accordingly, the DSE perspective works from a social model that examines the possibilities, cultural constraints, and political interests that shape differences in disabilities (Collins et al., 2016). Therefore, the concept of disability does not include only people who have some type of physical disability. Sexual identity, race, gender, class, and ethnicity are other forms of personal marginalization, marked by ableist inequalities. Deficit perspectives of race, disability, gender, class, sexuality, and language account for how ability and disability are defined and used to displace people toward marginalized, exclusionary, and even abusive educational environments. These cultural beliefs about disability and differences also account for teaching practices and educational policies being analyzed in recent times (Valente & Collins, 2016).

According to Connor (2019), the core principles of the DSE focus on contextualizing disability within the political and social spheres, prioritizing the interests, agendas, and voices of people labeled as disabled, promoting social justice and opportunities for equitable and inclusive education, and rejecting deficit models of disability. Another key principle is that physical spaces, environments, and practices must be modified to favor access to education for students with disabilities, instead of requiring that they over exert themselves to adapt to inaccessible spaces (Vidarte et al., 2022).

1.2. Inclusive Education and Studies on Disability in Education

This section addresses the relation between inclusive education and the DSE perspective, which proposes the decentralization from the predominant epistemology and ontology, as well as the decolonization of the concept of "normal" that has a racial and ableist view on bodies, minds, and spirits. These structures that internalize oppression and violence bring about political, social, and cultural impacts, which are manifested within institutions and discourses and entail consequences at the material and emotional levels that lead to exclusion (Figueroa & Hernandez-Saca, 2021).Specifically in the educational field, DSE promotes fully inclusive environments as they have proven to be beneficial for students not only academically but also socially (Clough & Corbett, 2000; Cosier et al., 2002; Ryndak, 2014). Hence, integrated access to curricula is promoted to the detriment of separate or functional curricula. Due to the inclusion movement, 90% of children are now included in mainstream educational settings for at least most of the school day (Bacon & Blachman, 2017).

There are notorious tensions regarding the concepts and practices related to inclusion. Although educational policies usually guide pedagogical horizons, ministerial regulations and/or guidelines are decontextualized in specific school realities. Furthermore, administrators or teachers consider them to be technocratic impositions, disallowing progress in the necessary structural and epistemic reforms within the educational systems, and thus resulting in practices that lead to new exclusions within such systems.

DSE allows for the unveiling of the "normality" myth, deeply rooted in educational practices. This results in the consideration of disability as opposed to normality, to indicate how students should be educated. Students with disabilities should be considered an important sources of information about disability, in order to focus on social justice. Consequently, inclusion will be understood as a commitment to adapt instructions for all students instead of requiring children accommodate to the status quo of the classroom or school structures. Inclusion is not something that is achieved once and for all but must be continuously and flexibly focused on depending on individual needs (Ferri, 2015).

1.3. Inclusion, New Technologies, and Visual Impairment

UNESCO, in its Sustainable Development Goal 4 (SDG 4) of the 2030 Agenda, proposes to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" by 2030. It also aims to combat all forms of exclusion and marginalization along with disparities and inequalities in access, participation, and learning outcomes. UNESCO is committed to making the necessary changes in inclusive education policies. One way to ensure an inclusion policy is to provide the teacher with the tools to address the diverse conditions of the populations in the classroom (UNESCO, 2015).

Although there is global legislation supporting inclusive education policies, the different ways of implementing pedagogical practices responds to political, cultural, social, and economic demands that emerge from the different contexts in which these are framed. According to Karagianni and Drigas (2023), given these characteristics, such practices should be guided by principles of universal design in order to provide the necessary educational resources and infrastructure that will ensure constant and permanent access to information and knowledge. New educational models are required in the general classroom, where the objectives must be designed for all students, with the implementation of pedagogical and teaching/learning strategies that incorporate the use of new technologies depending on the individual differences of each student.

These emerging challenges are the basis of this *metroSonus* proposal, resulting from the observation of the pedagogical practices with teachers in training in the area of arts education. This is due to the need to create pedagogical tools that respond to the particular educational needs of the different groups, in this case, the visually impaired.

The above is organized as the starting point for this research, which is the creation of a proposal for a technological tool that promotes inclusion in music training spaces, specifically, for those who want to be conductors of a musical ensemble, with the participation visually impaired performers, understood as the "various eye conditions and visual abilities" (Caballo & Núñez, 2013, p. 260) that cause from complete vision loss to different degrees of vision loss, known as "low vision" (Gray, 2009).

The specific search for relevant contributions in this field of study was conducted initially through the Information and Communication Technologies (ICT) and visual impairment categories, to identify research whose results contribute to proving the importance of using technology in the educational processes of visually impaired individuals. In the specific area of device development for this, only one similar proposal was identified called the "Haptic Baton."

As previously mentioned, research conducted in this field indicates that using technological tools favors the creation and development of pedagogical responses for the particular needs of visually impaired students. This is becoming an important way to reduce or eliminate learning barriers in the educational systems, which restrict opportunities for students to learn and participate in institutions (Echeita & Navarro, 2014).This is shown by the non-experimental descriptive research adopted through a mixed-method by Castro and Téllez (2022), which not only aimed at proposing a series of inclusive strategies mediated by ICT but also confirmed that ICT are a strategic means of social inclusion for strengthening the education of visually impaired students. Moreover, implementing this type of strategy is important for comprehensive quality education and to reduce difficulties, thereby allowing them to participate actively in any environment which promotes meaningful learning. Likewise, the goal of the research carried out by Castellanos (2019) is to set out pedagogical strategies that promote the educational and social engagement of blind people through ICT use. The socio-critical approach from the qualitative methodology allowed the author to conclude that strategies contributed to the identification of problems that limited the involvement of visually impaired students, in the development of autonomy and independence favoring active engagement and interaction within the school context. Similarly, ICT worked as channels for the freedom of expression that facilitated social interaction between students and teachers and helped achieve comprehensive quality education, which positively influenced their academic performance.

Zorz (2019) aimed to explore the impact of ICT mediation in the students' school performance and in the development, learning and construction of subjectivity. Based on an exploratory and descriptive approach, the author, in line with the previous research, concludes that the removal of barriers in the environment is crucial to developing the individuals' autonomy so that accessibility conditions are guaranteed. Thus, all students can take full advantage of the school experience and boost their learning. He furthermore indicates that technology helps resolve situations that were previously impossible or unattainable. This is due to the way knowledge is produced and distributed, therefore, enhancing the teaching–learning processes.

ICT can bring countless advantages to support the learning processes of the visually impaired, as they decisively support inclusion and participation, improve the quality of life, support the construction of identities, guarantee rights, and reduce inequality gaps, and significantly minimizing the risks of exclusion (Escobar-Morales et al., 2022; Martínez et al., 2022; Parra, 2022; Zambrano-Lozada & Zea-Tibaduiza, 2021).

1.3.1. Music Education, Visual Impairment, and New Technologies

This section specifically addresses the research on technological proposals from different perspectives and their implementation to strengthen the teaching–learning processes in music education of the visually impaired. These perspectives highlight the relevance of the problem under study as they present a wide range of creative proposals arising from the purpose of seeking alternatives to inclusive learning processes for the musical training of visually impaired individuals. From this perspective, Frid (2019) presents a review of accessible digital musical instruments (ADMIs), based on a systematic review of 113 publications focused on this topic. In the 83 instruments found, 10 types of interfaces could be identified: tangible controllers, contactless controllers, brain-computer music interfaces, customized instruments, portable controllers or prosthesis, mouth-controlled devices, audio drivers, gaze controllers, touch screen controllers and cursor-controlled interfaces. The author concludes that although the haptic modality could play an important role in the interaction between technology and music education, only 14.5% of the instruments found incorporated vibrotactile feedback.

The research proposals specifically focused on the haptic method allowed identification of the Haptic Baton, a high-tech device developed by Human Instruments, London, which comprises a baton with different sensors connected to a bracelet worn by the conductor. This bracelet transmits the pulse to a receiving device worn by the visually impaired musician somewhere on their body (Human Instruments, 2023). Along the same lines, Bajo et al. (2010) explains the development known as "DIAMI," an architecture based on a smart environment, focused on easing the integration of a visually impaired musician into orchestras. The DIAMI architecture provides a system for visually impaired musicians to receive instructions from the conductor in a discreet manner. From a design-based approach, the research proposes a device that uses a Nintendo Wii controller attached to the director's baton, from where it uses the internal accelerometer and gyroscope to interpret the intensity and speed of their arm movement to convert it into signals sent via Bluetooth to a vibration receiver in the form of a bracelet designed by them. Although both proposals are quite similar in terms of the vibrotactile need and overall concept, the technological development approach differs in both cases, and although both DIAMI and Haptic Baton fully meet their purposes, the potential costs of the devices (yet unavailable for sale) or the technological and financial capacity to produce them would substantially reduce their access for most of the population.

However, Gorbunova and Morozov's (2021) research concerns the implementation of specialized software and technology-mediated methodologies and addresses the creation and development of new music teaching techniques for the visually impaired by redesigning the traditional teaching methods and introducing music computer technologies (MCT). In music education for visually impaired students, MCT is no longer a promising innovation and becomes a reality by expanding opportunities for inclusion. Theoretical contents, such as music theory, harmony, counterpoint, and solfeggio, which in the past could only be taught verbally, are now innovative proposals that use new technologies to bring visually impaired people closer to these contents in a different way. After a documentary review, the research analyzes the methodological content aspects of teaching theoretical music content using MCT with visually impaired students in different institutions in Russia. It proposes methodological and content support for its teaching and determines methodological approaches to implement this educational process in practice. The relevance of the appropriation of theoretical contents such as "Computer Music Arrangement" and "Computer Music," both for personal growth and for social adaptation of visually impaired musicians in a high-tech educational environment that poses professional and social challenges, is one of the conclusions reached by the authors. Furthermore, there is the need to develop new proposals of specialized software to optimize music education for this population.

Similarly, Gorbunova and Voronov (2018) analyzed the processes concerning the transformation of the training environment of visually impaired students in the typo-technology class. Based on the case study, the research focuses on the results of the implementation of a methodology created by the research team in an environment also designed by them, as well as on the analysis of the specific characteristics of the learning process and the use of information technologies (IT) and MCT by visually impaired students. It concludes that with the right tools and environment, visually impaired individuals could not only master a number of MCT programs (sequencers, audio editors, and so on) but also significantly develop their creative potential using the technologies.

Based on the above-mentioned studies, the following research questions have been drafted: How to create an inclusive space where visually impaired and non-visually impaired musicians can be directed at the same time? Could this space be created and mediated by a technological device? Could this device guarantee the affordability and accessibility conditions within an inclusive social context that is useful for all individuals?

Along these lines, this paper aims to develop a technological proposal that contributes to the teaching–learning processes in an effective and flexible manner to fulfill the inclusive education requirements. This leads to the idea of creating a program that can recognize the pulse set by the conductor, turning their movements into pulses that are sent to the mobile devices of visually impaired musicians and transformed into vibration. Thus, the objective of this research is to design a web application that transmits the conductor's pulse to networked mobile devices to support the teaching–learning processes and music interpretation for the visually impaired

2. Design and Method

The initial process of this study focused on the identification of two major research points, which guide and characterize the specific objectives required to achieve its global purpose framework. The combination of theoretical and empirical approaches helps address the methodological parts that constitute this strategy and allows for the study of the problem identified in the preliminary stage. On the one hand, the goal of *metroSonus* is to provide new knowledge, technological development, and innovation from the diverse areas of knowledge. This is carried out with disciplined and planned structures where constant experimentation plays an important role in achieving the final product. The nature of each stage of research requires a specific methodological approach as they are specifically established, while still forming a whole, in terms of research.

Based on the qualitative paradigm, the general methodological framework is conceived from a praxeological approach (Juliao, 2011).In this case, it is directly related to the Creative and Cultural Industries as contributors to the knowledge generation, technological development, innovation and social appropriation of knowledge within the R&D+I (Research + Development + Innovation) CTeI Ecosystem category, as defined by the Ministry of Science, Technology and Innovation of Colombia (MinCiencias, n.d.).

The praxeological approach (Juliao, 2011) is understood as a process that aims to transform reality through observation, reflection, and constant inquiry. The characteristic methodology and instruments in praxeology research undergo constant redefinitions for raising awareness of the elements reflected throughout the study. Therefore, the uniqueness of each study and the possibility of adapting it to its disciplinary field and context are assumed, for which a series of principles, suggestions, and indications that enable its implementation are proposed. The following is a summary of the stages that guide and characterize the praxeological/research actions proposed by Juliao (2011).

The first stage consisted in observation. This is the search and analysis/synthesis stage, cognitive in essence, during which the researcher/praxeologist understands the problem and raises awareness of it. At this point, a lot of information was collected, analyzed, and synthesized. This resulted in the consolidation of theoretical knowledge and practical readings as a basis for the overall understanding of the research problem

The second stage was for judging and evaluation. This is the reaction phase, substantively hermeneutic, during which the researcher/praxeologist forms their own interpretation of the problem and develops the necessary empathy to participate in it. Here, the methods used for observation and experimentation were drawn up, the two working dimensions were structured and defined. This lead to the action to achieve each one of them: the prototype development and implementation by conducting technical and functional tests with a focus group.

The third stage was action taking. This is the stage in which the practice undergoes an operational re-development process, essentially pragmatic, wherein the researcher/praxeologist constructs the complete and directed management of procedures and tactics. It moves from experimental research to practical application. At this point, from the technical perspective the device was developed accordingly with the necessary software development processes. Later, the inquiry protocol was structured, making the development of field work in simulated and real environments through focus group work possible.

The fourth stage consisted of creative feedback. This is the reflection stage for the action taken, mostly prospective, answering the question: What can be learnt from what was carried out? This foresight represents an *a priori* future, an ideal, an aim,, anticipation, and an evaluation. Due to the information collected in the fieldwork, from the experiential and technical perspectives, adjustments were made to the device in terms of software, applicability, and use, in order to deliver the results of the research from a planned implementation and evaluation process.

MetroSonus was assessed in accordance with the Technology Readiness Levels (TRLs), a concept developed by NASA to evaluate aeronautical projects. It was later adapted to be applied to any project, from its original idea to its deployment (Ibáñez, 2014).

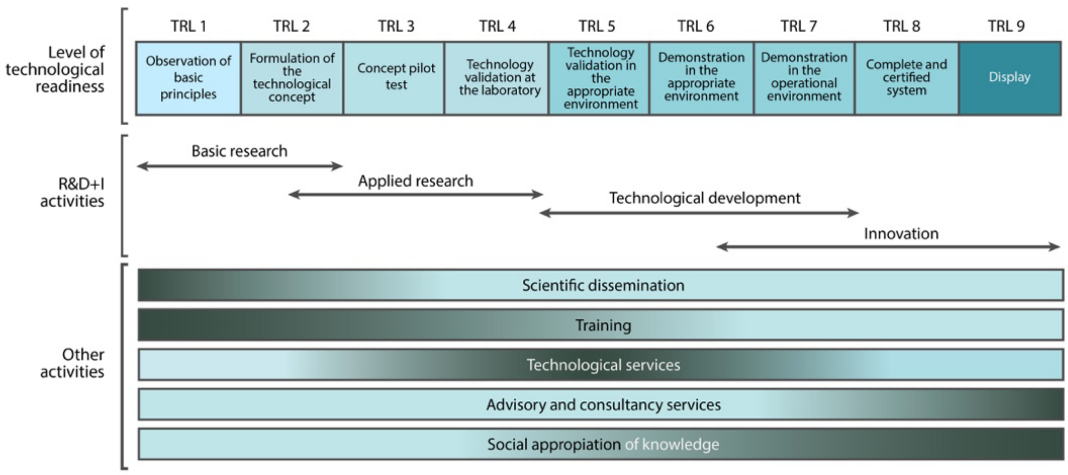

Figure 1. TRL, R&D+I and other activities.

According to the NASA website, each technological project is evaluated considering the parameters of each technology level, to later assign a TRL score based on the progress made by the projects. There are nine technological readiness levels, with TRL1 being the lowest and TRL9 the highest (Tzinis, 2014). The following chart (Figure 1) associates the scope of the different research and R&D+I stages with the different TRLs.

Note: Adapted from National Science, Technology and Innovation Policy No. 1602. Actors of the National Science, Technology and Innovation System. (p.12), COLCIENCIAS, 2016.

To conclude, this study's methodological design seeks to address different perspectives through the specific characteristics of the methods used. The aim is to obtain an approach based on the distinctive features and generalizations of reference analysis, as well as their interpretation, based on research objectives and set up. Therefore, during the research, some dimensions may prevail over others or be developed in parallel, depending on the requirements of each stage.

3. Fieldwork and Data Analysis

The overall fieldwork process in the research was carried out with two general dimensions: prototype development and implementation. The first stage was structured according to the TRLs, based on the observation of basic principles by the software design team, resulting in the applied research (TRL1). Thereafter, the *metroSonus* concept was introduced, along with the practical applications that oriented the invention (TRL2). Analytical and laboratory-scale studies were conducted to validate the analytical predictions of the proposal (TRL3). In these three levels, there is a movement from basic to applied research, corresponding to the device development dimension.

Then, the implementation stage began with development validation in a laboratory setting, confirming the functionality as the system of the various components working together (TRL4) and then leading to the validation of *metroSonus* in the appropriate environment. To this end, tests were carried out from September to November 2021 in simulated environments with students of UNIMINUTO's Bachelor's Degree in Art Education (TRL5). Finally, the product was demonstrated in a suitable environment at the facilities of the National Institute for the Blind of Colombia (INCI), with a *metroSonus* pilot prototype (TRL6). Moreover, these three levels correspond to the technological development stage, where implementation tests are carried out.

In the second stage, a technical test was conducted in a simulated environment with students at the university facilities. Subsequently, a protocol was developed to guide the technical and functional test in a real environment, through a focus group comprised of 10 visually impaired musicians (with empirical and professional training).

The protocol was designed in such a way that it could inquire into the categories of analysis of the research framework. This was based on three main categories, the first one which addressed questions about navigation, clarity of instructions included in the web page, and elements to be preserved, removed, or improved. The second category addressed technical and operational aspects regarding the perception of vibrations, pulses, and synchrony. Finally, a third category on the pedagogical possibilities where contributions to music teaching–learning processes were explored, along with their usefulness for orchestra ensembles and visually impaired musicians, as well as how this tool aids in the inclusion of this population.

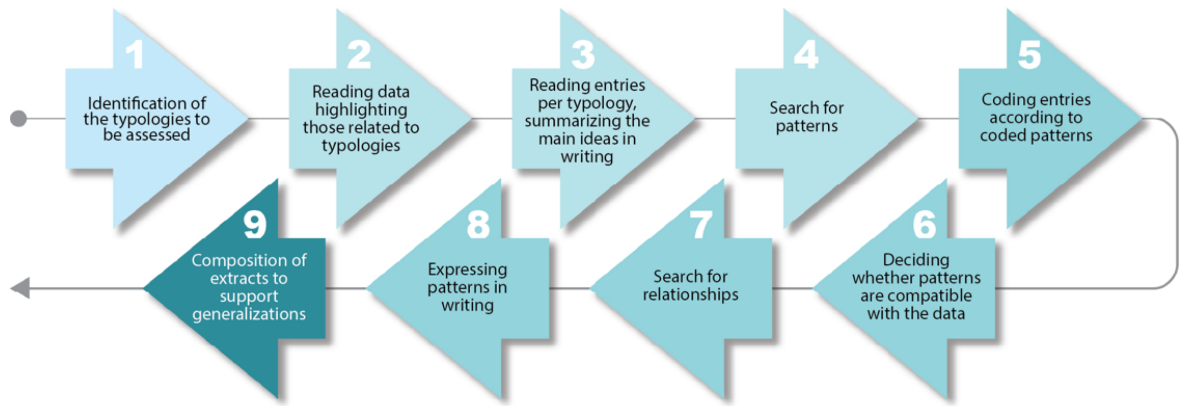

Figure 2. Steps towards typological analysis.

After information was collected from the focus group, recordings were transcribed using Microsoft Office and anonymized to protect the participants' identity. Following the methodological orientation of Hatch's Typological Analysis (2002) (see Figure 2), the data were analyzed and coded in an open way by the authors using the Nvivo software, creating the following analysis categories: accessibility, functionality of the application, pedagogical use, inclusion, and usability in orchestras and ensembles. Key aspects regarding *metroSonus*'s strengths, weaknesses, and areas for improvement were also collected.

Note: Adapted from Hatch (2002).

4. Results

The results are collected from the various research stages proposed in the praxeological approach (Juliao, 2011), which allowed for the consolidation of the application development and its scopes at the technological level, as well as the prototype implementation through the field tests conducted. Hence, the research findings are based on two well-defined working dimensions: prototype development and prototype implementation.

4.1 Prototype Development

As in any software development process, the analysis stages began with a search for references and contextual readings, allowing for the proposal definition and design, in accordance with TRL1 and TRL2. As a result of these first stages, many technical decisions were made based on the needs and restrictions of the project, and the initial technological concept was formulated: the application should easily enable visually impaired users to receive the necessary rhythmic stimuli in a rehearsal or musical presentation including the participation of a conductor, with minimal impairment of the directing task.

The following needs were identified from the analyses conducted during this phase:

- Easily affordable by any user at a global level
- Not be dependent on licenses or libraries
- Easy to maintain and support
- Allow for real-time image capturing and processing
- Track the conductor's movements
- Communicate through the musicians' mobile devices

The above led to the implementation of a publicly available web application to allow its use in several devices, created in standard development languages to reduce dependence on third-party software and facilitate its maintenance.

In view of the need for high availability so that it be accessible to any user without any additional costs and it work on several devices simultaneously, whether desktop or mobile, the web application was developed to run on a web browser. This implied several technical challenges due to the environmental restrictions, i.e., access to device functionalities such as vibration or display settings on mobile devices. Therefore, the technological concept (TRL3) generally requires a client–server architecture with which each client can select a role (conductor or musician) in a room that can only be created by the director, who communicates with all musicians connected in the same room.

This concept encompasses two different user interfaces, one for each of the possible roles:

- Director
- Musician

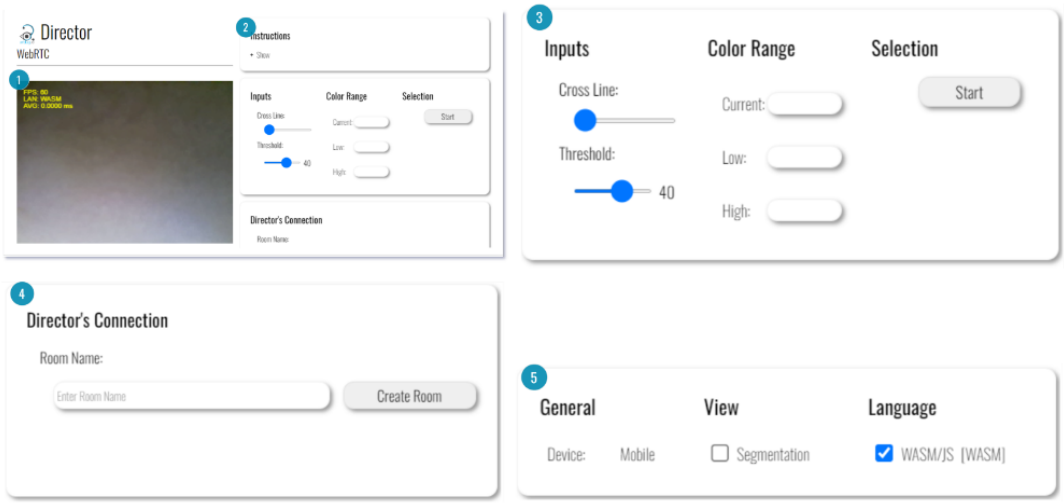

Figure 3. Directors' interface.

The director's page is divided into two sections: one with access to the camera and the data associated with real-time video processing (1) and the "Settings" section (2). In the latter, one can choose the color to be used to monitor the pulse, the responsiveness of the image segmentation process, the point chosen to transmit the beat to the musicians, the language to be used for real-time processing (5, 3), and everything related to the creation of the room and connection with the server (4).

As for the musician (player), a much simpler user interface was employed, just including the control panel to connect to the musician's desired room and the preferred notification type (vibration or audio). The chart used to visually indicate a received signal was shown regardless of the notification type is selected.

To host the online web application, the website http://www.artilug.io was created, following the requirements to ensure easiness of access and understanding. Accordingly, a minimalist design with little text was chosen to avoid distractions caused by screen readers and other applications used by the visually impaired population.

Figure 4. Musicians' interface.

Regarding the *metroSonus*'s methodology of usage, the process was also designed to facilitate the process of accessibility. The director visits the website and clicks on "Director" in the *metroSonus* section, following the instructions shown on the screen. Next, they name the rehearsal room or space and click on "Create room."

On the other hand, the visually impaired musician visits the website, but in the *metroSonus* section and clicks on the "Player" button. Thereafter they enter the name of the room assigned by the director and click on "Connect." Henceforth, all musicians connected to this room will start receiving the vibrations sent by the directors' gestures on their mobile devices, as explained by Gaitán in the introductory video for the operation of *metroSonus* (Gaitán-Lozano, 2022).

Directors only need the following to use *metroSonus*:

- Internet connection
- Web browser (Google Chrome is strongly recommended)
- A colored glove or baton

The musicians only need the following:

- Internet connection
- Android OS mobile device

4.2 Prototype Implementation

Due to the nature of the praxeological approach adopted, at this moment, results mostly vary between the third and fourth stages, dissociated from the traditionally established linear moments. In the beginning, the technological concept was tested in the laboratory, corresponding to TRL4. Its basic components and their operation were evaluated both separately and as a whole in different operating systems and on various mobile devices with satisfactory results. This led to a preliminary design of the prototype that would enable subsequent testing in the field.

Next, validation was carried out in simulated and real conditions with the students (TLR 5), where the tool itself was tested, along with its accessibility and technical and functional aspects, explored by means of a research protocol. This made it possible to return to the prototype and resume the process of experimentation and technological development. The findings obtained from these tests in simulated environments led to relevant changes in the prototype. Most were related to modifications in the graphical interface and some connection problems, which finally resulted in the development of the minimum viable product, the ready-to-use version of *metroSonus*.

As a result, TRL6 led to the prototype demonstration under conditions relevant to the actual operating conditions, at the facilities of the INCI in this case, with the participation of 10 visually impaired musicians. The test included the staging and performance of a simple piece of music by all participants supported by *metroSonus*, followed by an inquiry about the aspects defined in the research protocol.

In both groups, the inquiry process took place through focus group work. The coding process of the information gathered and its subsequent analysis, as well as the repetitions and reiterations of the *metroSonus* prototype, helped summarize the following results from the identified analysis categories. Moreover, both the positive aspects and ways of improvement are considered for the subsequent and continual tool development. The following sections contain comments and feedback in italics about this prototype.

4.2.1 Accessibility

Participants considered that the site was user-friendly and well-designed, and they believe that visually impaired people can use it without any problems:

> The site is okay as it can be easily understood, and the visually impaired individual who wants to visit it can easily do so

The tool was described as pretty didactic material, highly versatile both for visually impaired individuals and sighted users.

> The page seems minimalist to me, that is, it is quite interesting, but, well, I don't know if the page is only for blind people because the format doesn't matter; if it is also for sighted people, it would be interesting if it were minimalist, but with a touch of something else.

Another aspect was the free cost of the application, which was highlighted as a positive feature:

> "If I have to say something regarding the application, I would highlight that it is free, which is really cool. Yes, we have to be aware of the fact that you need money to survive and cannot pretend that it will always be free".

About the use of the tool through iOS operating system, the following should be considered:

> "Yes, let's say we need... we also need to make sure that it is compatible with all cell phones because some of us were unable to participate because of that aspect."
>
> They remarked that a good connection is required for the proper use of the site:
>
> "After using the site for some time, it was also blocked".

One suggestion was that the tool could be connected to the voice assistant, and were a mobile App (application) as this might make it more accessible in rural contexts where connectivity is not optimal:

> "...it should not be a web page, but an application so it would be easier to use in rural areas with limited Internet connectivity".

4.2.2 Functionality of the application

The time required for the application to be set up stands out as it was considered sufficient for its use within a work group:

> This is positive because sometimes, if you need to use it for a concert, you are like... wait, I must set up the app, and it may take up to half an hour, right? I mean... that would not be so great.

Minimal mismatches were observed between the participants' signals:

> There was one that kind of got stuck, that is, there were some parts where it got stuck and it kind of... the tempo shown on the screen was not the correct one. Then, the vibrator and the other tempo came along together and in a row. So, there was a delay... although quite minimal.
>
> Some participants also said it was not possible to activate the vibration.

More advanced development stages should be implemented, and its use should be extended so more people can try this project.

> The good thing is that, hopefully, in all realities, the project goes down in history and actually grows, and I agree that it should not just be limited to its use within the university setting.

Users found the vibrator feature to be convenient than the whistle as it more adaptable to use.

> I agree with (Participant No. 2) the whistle use... as a visually disabled user, I think that the vibration is more convenient in sensory terms than that whistle.

Recommendations were made about the location of the device for optimal use and functionality.

> I think it depends on where the device is located, right? It is much more perceptible on the hand than on the thigh or on the chest because I think that the vibration, obviously, cannot be so strong, but I don't know if it depends on the cell phone used.

4.2.3 Pedagogical use

An importance aspect of the tool is that it can be used others, not only by the visually impaired..

> – Totally, what I was saying, not only for blind people but for all kinds of users, sometimes it is also very difficult to get close to that beat, to that constant pulse.

– Besides, well, people understand music visually, but also by feeling it, so I think that would also be a great methodology for people who can see too.

The diversity of use for different types of needs is highlighted.

– Also, let's say that if the person has not developed a musical ear, they can really recognize it from the senses, and that is quite interesting.

– It would be great or interesting to test it; well, I don't know if it's crazy to think about it, not only through sense of touch, but as you say on the leg; I did it by touching, and I think most of us did it with the hand. I'm not sure how well it will work using the foot and by people who don't have hands.

Participants emphasized how the tool motivates users to learn.

I think it's really cool… super interesting, you feel more like making music. I think it's great.

They highlight how the technological tool can support attention processes for visually impaired people.

– I feel happy that I could be part of this group because even very little children can get it… I mean, it's a device that gets their attention.

– Yes… that's why I said; focused attention must be kept… not selective, but total focused attention on the instrument and what is being played.

This tool is important for overall activation and perception through the senses, not only at the auditory level.

Besides, it provides a more direct interaction with the senses, not just the auditory one, but feeling the pulse… feeling it, not just listening to it but feeling it.

4.2.4 Utility in orchestras and ensembles

This is regarded as a useful tool, especially for orchestras or very specific performances. However, the perception is different for popular music:

> I think it's useful, as I said at the beginning, for classical music and very specific performances, or stuff like that. I can tell each popular orchestra has its own method, and now, I think you know more than me about this., Suddenly, in certain events, technology allows you to have your director there talking to you without the need for the public to hear it, as for the question of how sound is currently handled. So, if you ask me, I would say (it's useful) for orchestras and for very specific band projects… and that's like everything. This is not the case of popular music like jazz since it is more about improvisation and connecting with music. I believe that to connect, you don't need… I mean, sighted people look at each other, but I think you can have a connection with them without that, but knowing, as he just said… paying attention to what is being played, keeping focused, and in that aspect it can help us a lot.

The tool allows visually impaired people to be part of large music ensembles.

> The goal of this pilot is for orchestras not to reject a blind musician, simply because they don't know how to tell them when to start playing… you know? Because in a small orchestra, he may give oral cues, but in a big one… with each musician having to participate several times… that is what it will allow me to do… so I don't stop conducting the orchestra in front of them and have to say: "Jonathan, your turn," or "Laura, you go now."

4.2.5 Inclusion.

The tool is functional and eliminates barriers that visually impaired musicians experience when playing instruments with sighted people:

> If you are going to use it with someone who is in training, it will help a lot because sometimes you have that deficiency with blind people, when playing in a group… and maybe it's you, not them. One can have a good ear, and they tell you: you are going too fast, something that sighted people can do with their score. I tell that person who is tapping you on the shoulder all the time saying: "don't go fast, slow down"… the voice of our conscience.

The need arises for the visually impaired population itself to disseminate and encourage the use of the device as part of their inclusion processes.

> Because sometimes we all think "oh, poor blind people! We are never include." Look, music teacher, this strategy, which of course is going to work (I already tried it), because the teacher doesn't know it all either… as you are already grown up, you approach a teacher and say: "look, I used this application that allows us to do this and that…" So yes, we should also suggest the places… let's see how actually include ourselves as well.

Once again, it's outstanding how this device can be used to respond to the educational needs of other populations.

C1. For everyone's inclusion, you know? I think that using the term "inclusion" for just blind people is not fair… we must include everyone that may find this application to be useful too.

C2. In my case, I suffer from hearing loss… and I was thinking it is really useful because sometimes it's really difficult for me to feel or hear the beat, but feeling the vibration is great. The little square is also useful as it guides us… lights are synchronized with the director… also in terms of speed, so that also serves as a visual guide for rhythm, so to speak.

Table 1. Focus groups results.

RESULTS	
CATEGORY	**RESULT**
Accessibility	Participants considered that the site was user-friendly and well-designed, and they believe that visually impaired people can use it easily. Summarize as: User friendly, well designed, convenient for visually impaired
	The tool was described as good didactic material, highly versatile both for the visually impaired and users with sight. Summarize as: Good didactic material, flexible use for all types of learners
	The free cost of the application is highlighted as a positive feature. Free cost
	The use of the tool through the iOS operating system should be considered. Adapt to iOS operating system
	A good Internet connection is required for proper use. Requires good internet connection
	Suggestion: the tool could be connected to the voice assistant, and it would be great if it could be developed as an application. This would perhaps make it more accessible in rural contexts where connectivity is not optimal. Suggestion: connect tool to voice assistant, develop as an application for accessibility in rural settings.
Functionality of the application	The time required for the application to be set up stands out, as it was sufficient for its use within a work group. Set up time is sufficient for work groups.
	Minimal mismatches were observed between the participants' signals.
	More advanced development stages should be implemented, and it should have more extended use, to make this project available to others. Continue develop and apply to a wider context.
	Users found the vibration feature more convenient than the whistle, as it allows for greater adaptability of use. Vibration more convenient than whistle function.
	Recommendations are made about where to keep the device for optimal use and functionality. Where the device should be placed for optimal use and functionality.
Pedagogical use	The importance of the tool for its use not only by the visually impaired but by people with sight. For visually impaired and all types of users.
	The diversity of its use for different types of needs is highlighted.
	Participants emphasized how the tool motivates users to learn. Motivates learning
	They highlight how the tool can enhance attention processes for the visually impaired. Enhances attention processes
	This tool is important for the overall activation and perception through the senses, not only at the auditory level. Overall sensory activation and perception
Usability in orchestras and ensembles	This is regarded as a useful tool, especially for orchestras or very specific performances. However, its applicability would be different for popular music. Especially for orchestras and bands. Popular music and jazz have different ways of functioning
	The tool enables inclusion of the visually impaired in large music ensembles. Inclusion of visually impaired in large music ensembles
Inclusion	The tool is functional and eliminates barriers that visually impaired musicians experience when playing instruments with people with sight. Functional tool, eliminates barriers for visually impaired.
	The need arises for the visually impaired population itself to spread the word and encourage the use of the device as part of their inclusion processes. Visually impaired musicians should be aware of this tool and promote its use.
	Once again, it is evident that this device can be used to respond to the educational needs of other populations. Device supports a range of educational needs for inclusivity.

In conclusion, the *metroSonus* web application has been validated under conditions similar to the mentioned operating ones. It could be observed that it represents a prototype of detailed design that meets the required scaling conditions that would allow it to reach a fully operational system. Moreover, it is capable of performing all required functions, so the proposal's TRL corresponds to TRL6.

5. Discussion and Conclusions

The use of a device like *metroSonus* helps incorporate crucial elements for the promotion of pedagogical or professional practices in the framework of accessibility principles and universal environments. Similarly it opens up opportunities for participation in processes of equitable and inclusive education, according to the principles proposed by Connor (2019). According to Vidarte et al. (2022), the positive results achieved in the fieldwork through the implementation of the device consolidates the idea that it is the practices, educational environments, and physical spaces that need to be changed, based on the principles of the universality of learning, to support and guarantee access to education and participation of each and every individual. *MetroSonus* creates inclusive music learning and/or musical practice environments, as reflected in the participants' perceptions of their experience using the device. Favorable and positive aspects were demonstrated not only at a pedagogical level, but also in the emotional and social dimensions, these being mandatory indicators when referring to general educational environments as proposed by Bacon and Blachman (2017).

In line with the principles proposed by DSE (Ferri, 2015), using this device contributes to our strengthened commitment as educators to adapt the instructions and teaching/learning strategies to each student. This counterposed the ideology, focused on student deficiency, where they must find ways to adapt to the conditions established in their classrooms or educational spaces.

The use of *metroSonus* as a technological tool in the learning processes of the visually impaired is a major step forward to eliminating learning barriers and guaranteeing accessibility and full participation. Furthermore, it supports the comprehensive and quality education of students by reducing difficulties and supporting their learning, autonomy, independence, and interaction (Castellanos, 2019; Castro & Téllez, 2022; Echeita & Navarro, 2014).

5.1 From the Prototype Development

As this tool is designed for universal access, the needs that it supports must be considered from global and general conditions of the contexts and the user population, in this case, the visually impaired. The client–server architecture allows for the creation of simultaneous rooms, which can be comprised by a director and the group of musicians. Thus, in an educational institution, this exercise can be simultaneously conducted by different groups in different spaces. It is a free tool in the form of a web application, which does not require any software installation, therefore favoring its accessibility and affordability. As use of the tool, the musician can feel the pulse through haptic, audio and visual methods, thereby allowing the spectrum and scope of pedagogical actions to be broadened, depending on the specific needs or preferences of the user and/or counselor.

5.2 From the Prototype Implementation

From a pedagogical perspective, the tool can be useful for other special needs groups and for other methodological and didactic proposals. Hence, it can be adapted to other educational settings. As a device that blends innovation and technology, *metroSonus* arouses user curiosity, which later turns into motivation for learning or interpreting music. The use of *metroSonus* can support attention and concentration processes in music learning for the visually impaired.

metroSonus specifically promotes the inclusion of the visually impaired as it facilitates not only their performance, either as learner or a musician forming part of an ensemble, but also of their counselor or director with no specialized technological knowledge, other than that obtained from regular practice. The tool can be used to harmonize a working relationship with an ensemble of musicians with or without special needs. Given its open and flexible nature, the results of this research and its creation are consolidated, resulting from knowledge boosting developments based on use in other fields. Moreover, it is well established as a continuous and flexible field, that can be modified and improved by other users who are interested in software development.

These expectations become new possibilities for this research team's exploration and fulfillment. Moreover, they pave the way for new routes of development and possible further similar research and joint work with other organizations or institutions interested in the research area, constituting essential practices focused on its development along with professional, teaching, and personal growth. This research project poses new training challenges and demands in the various areas explored for the development of *metroSonus* and in those areas that are required to continue this project, such as computer vision, machine learning, and artificial intelligence.

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Abbreviations

ICT: Information and Communication Technologies

ADMI: Accessible Digital Musical Instruments – Instrumentos digitales musicales accesibles.

BCMI: Brain Controlled Musical Instruments – Instrumentos musicales controlados por el cerebro.

IT: Information Technologies – Tecnologías de la información

MCT: Music Computer Technologies – Tecnologías informáticas musicales.

TRL: Technological Readiness Level – Nivel de madurez tecnológica

INCI: National Institute for the Blind of Colombia – Instituto Nacional Para Ciegos Colombia

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