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Music Education with Artificial Intelligence for Inclusive and Sustainable Early Childhood Learning

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Abstract

This study aims to evaluate the impact of a didactic strategy that incorporates generative artificial intelligence (AI) into music education, supporting oral language development in preschool children and promoting inclusive and sustainable early childhood learning. Using an action-research approach, a mixed-methods design was applied to assess the performance of 15 children aged 3 to 6 years, divided into experimental and control groups. The experimental group participated in AI-supported activities using tools such as Genially, Educaplay, and Wordwall, whereas the control group employed traditional methods. Quantitative data from pre-and post-tests, as well as qualitative observations, revealed that AI-enhanced sessions improved motivation, pronunciation, and engagement, particularly among children aged 5 and 6 years old. Although statistical tests showed no significant differences between groups, the intervention demonstrated pedagogical effectiveness by increasing interest and participation. The novelty of this work lies in applying generative AI in early music education to personalize learning and reduce inequality, aligning with several Sustainable Development Goals (SDGs 3, 4, 9, and 10). The findings offer valuable insights into designing inclusive educational experiences through the integration of ICT and AI, highlighting the need to enhance teacher training in emerging digital pedagogies and promote accessible music-based learning in diverse educational settings.

Keywords:

Artificial Intelligence Tools;
Innovations;
ICT;
Sustainable Development Goals (SDGs);
Learning in Music.

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1- Introduction

Language acquisition begins in infancy and is significantly enriched during preschool education [1] when educators play a fundamental role in fostering communication skills. Music is a powerful and engaging tool for enhancing speech and language development. However, many teachers lack formal music training [2], often feeling unqualified or reluctant to incorporate music into their teaching practices. This project aims to empower educators with practical music resources and ICT tools [3], enabling them to integrate music effectively into language development activities.

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The relationship between music and language is deeply rooted in shared elements such as rhythm, intonation, and auditory discrimination. From early childhood, humans demonstrate sensitivity to sound, which underpins linguistic and musical learning [4]. Music stimulates multiple areas of the brain, creating a multisensory experience that enhances phonological awareness, supports interventions for language disorders, and improves pronunciation and vocabulary acquisition. For example, rhythmic activities and nursery rhymes can develop speech organs, foster emotional bonds, and promote social interaction.

Play is another essential aspect of preschool education. Together with music, the play offers a dynamic and enjoyable approach to learning, effectively engaging children in the curriculum's objectives. ICT tools further enrich [5] this process by fostering computational thinking, creativity, and autonomy. With their interactive features [6] and engaging animations, they capture children's attention and improve motivation, making learning more effective and enjoyable. This study is significant, as teaching is not based solely on the acquisition of technical skills but also on social, expressive, and inclusive skills [7].

Despite the abundance of musical resources available, many are too complex for young children. This project addresses this gap by compiling a collection of simple, ICT-supported musical activities tailored to preschool teachers [8]. These resources focus on rhythm, movement, auditory discrimination, and children's songs, providing an accessible introduction to music while stimulating cognitive and linguistic development [9]. In this way, the current digital divide, where not all students have access to AI tools due to economic, linguistic, or geographical barriers, can be bridged to some extent, bringing teachers closer to the simple use of some resources [10].

The ultimate goal of the project is not to create professional musicians but to train individuals who are sensitive to the educational potential of music [11]. Music contributes to social bonding, the acquisition of values, artistic sensitivity, and well-being. Research suggests that incorporating music into early education [12] enhances interaction, attention, and socialization, thereby promoting holistic development. Although we are faced with current models based on deep learning, which handle large volumes of data and require advanced software, prioritizing objective quantification without addressing the cultural background of students, we want to bring technological resources to teachers in any context so that they can be leveraged [13].

Teachers require training in AI-mediated resources, as these are very current technologies that we are faced with. There is evidence of insufficient technological training for teachers, and although the importance of training in this area is recognized, many teachers feel unable to address it in their music classes [14]. Music education is an opportunity [15] that opens doors to the comprehensive and inclusive development of children, taking into account diverse cultural contexts. The effective integration of ICT, multimedia applications, and AI in the training of future educators can significantly enhance educational quality and prepare students to navigate the challenges of an evolving digital world [16].

There is still a long way to go in terms of integrating AI into music teaching and learning processes [17], but starting to generate experiences that bring children closer to it can be a significant contribution to preschoolers who will be the adults of our society tomorrow. Hybrid, adaptive, and creative models could be created that integrate AI [18], promoting personalization and access to music education for all.

To achieve these objectives, a mixed-methods study was conducted using a quasi-experimental, exploratory-descriptive design. The study investigates the impact of a teaching strategy that integrates music and ICT on the language development of preschool children. The central research question is: How does the integration of music through ICT influence language development in preschool children?

This article is structured as follows: the first section reviews the relevant literature on music and language development, highlighting the benefits of ICT integration. The second section outlines the methodology and resources used to evaluate the proposed teaching strategy. The third section presents the research findings and statistical results, demonstrating the effectiveness of the approach. The final section discusses the implications of the findings, offering conclusions and recommendations for future educational practices.

Recognizing the value of music in the comprehensive development of children, this project advocates for its integration into early education. Equipping teachers with the knowledge and resources to use music as a language development tool can foster inclusive, equitable, and enriching learning experiences for all children. This work contributes to achieving sustainable and impactful educational outcomes through the synergy of music, play, and technology.

2- Background and Related Works

Language development during early childhood is crucial for laying the foundation of communication and cognitive growth. Researchers and educators emphasize the importance of this stage, as oral language acquisition has a significant impact on future academic success and social interaction [19]. In this context, music has emerged as a versatile and effective tool for language development, owing to its multisensory and cognitive stimulation [20].

2-1- Music Education and Language Development

The relationship between music and language is supported by shared characteristics such as rhythm, melody, and intonation, which are critical for phonological awareness and verbal expression [21]. Research indicates that engaging in musical activities can enhance speech articulation, vocabulary, and linguistic processing in young children. Furthermore, structured musical interventions have effectively addressed language disorders, such as dyslexia, through rhythm-based activities [22].

Preschool education relies heavily on play-based methods to enhance learning, making the integration of music a natural and impactful strategy. Teachers, however, often face challenges such as a lack of musical training or confidence in using their singing voice, which limits the potential of this resource. Addressing this gap requires equipping educators with practical tools and strategies to incorporate music into their teaching practices [9] seamlessly.

2-2- Artificial Intelligence in Music Education

Recent advances in artificial intelligence (AI) have opened new pathways for integrating technology into education. Generative AI tools [23], such as those used in this study, offer personalized and interactive learning experiences that cater to diverse student needs [24]. By automating the creation of musical content and providing dynamic feedback, these tools enhance cognitive engagement and accessibility, thereby improving the overall user experience.

AI's role in fostering inclusivity aligns with the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), SDG 9 (Innovation and Infrastructure), and SDG 10 (Reduced Inequalities). Studies have demonstrated that AI-based platforms promote equitable access to education by adapting learning content to individual capabilities and supporting students with special needs [25].

2-3- ICT and Musical Pedagogy

Information and Communication Technologies (ICT) complement AI by providing platforms for interactive musical activities. Tools like Genially, Wordwall, and Educaplay allow educators to design engaging learning modules [26], from rhythm exercises to instrument recognition games. These technologies captivate children's attention and enhance their ability to internalize abstract concepts through visual and auditory stimuli [27].

The integration of ICT and AI into music education has been found to significantly boost motivation, memory retention, and creativity among preschool students. Studies also emphasize the importance of incorporating physical interaction with instruments alongside digital resources to create a holistic and practical learning environment.

2-4- Implications for Teacher Training

Teacher training must be prioritized to fully realize the potential of AI and ICT in early childhood music education. Research highlights the need for continuous professional development to familiarize educators with digital tools and innovative teaching methodologies [28]. Training programs that combine theoretical knowledge with hands-on practice enable teachers to implement technology-enhanced music education strategies confidently.

This study builds on the existing literature by examining the intersection of music education, artificial intelligence (AI), and language development. Through a mixed-methods approach, it evaluates the impact of generative AI on preschoolers' linguistic and musical skills, offering insights into the transformative potential of technology in fostering inclusive and sustainable education.

3- Material and Methods

This study employs a mixed-methods approach, integrating qualitative and quantitative techniques to examine the impact of ICT-mediated music education on the language development of preschool children. The methodology compares an experimental group exposed to generative AI-supported activities with a control group that engages in traditional teaching practices. The study's design aims to evaluate outcomes in concept assimilation, pronunciation, and engagement in musical learning.

3-1- Context and Rationale

Conventional music education often emphasizes rote memorization and repetitive exercises, limiting creativity and individualized learning opportunities. This research introduces an innovative teaching framework tailored to children's unique needs by integrating generative AI. AI-generated resources [29], such as custom melodies and interactive activities, enrich the educational process, fostering inclusivity and enhancing cognitive, emotional, and creative development. The approach draws from action research principles, ensuring a continuous cycle of planning, action, observation, and reflection.

3-2- Participants

Fifteen preschool children aged 3 to 6 from a private educational center participated in the study. They were randomly divided into an experimental group (ICT-based activities) and a control group (traditional methods). For eight weeks, each group participated in weekly 60-minute sessions focused on identical musical topics but with different instructional approaches.

3-3- Resources

To create an engaging and inclusive learning environment, the following resources were used: 1) Digital tools: Platforms such as Genially, Educaplay, and Wordwall supported the design of interactive activities, while YouTube provided animated educational content. 2) Musical instruments: Xylophones, tambourines, and claves enabled active participation and sound exploration. 3) Educational songs: Short, thematic songs enrich vocabulary and improve rhythmic skills. 4) Visual aids: Colorful illustrations of musical instruments and symbols supported the visualization of concepts. 5) Assessment tools: A Likert-type questionnaire measured progress in musical concepts and pronunciation, while structured observations captured qualitative data on participation and motivation. The instruments were validated by the researchers, with the support of two experts in the field, to ensure consistency with theoretical frameworks and to make relevant adjustments to ensure conceptual reliability.

3-4- Procedure

1) Planning: A diagnostic test was developed to assess baseline knowledge of musical concepts. Based on the results, personalized teaching sequences were designed, integrating AI-generated activities for the experimental group.
2) Action: Weekly sessions involved distinct methodologies. Experimental Group: Engaged with AI tools for melody creation, rhythm exercises, and interactive quizzes. Control Group: Utilized visual aids, hands-on interaction with instruments, and teacher-led activities. Both groups addressed the same musical themes, including instrument recognition, rhythmic patterns, and note intonation.
3) Observation: Researchers systematically monitored children's responses, documenting qualitative insights through a checklist. Observations highlighted differences in engagement, participation, and learning progression between groups.
4) Reflection: Data from pre- and post-intervention assessments were analyzed, informing discussions on the effectiveness of the methodology. Statistical tests, including the Shapiro-Wilk and Mann-Whitney U tests, ensured a rigorous evaluation of the results.

Figure 1 presents a diagram illustrating the methodological procedure used in Action Research.

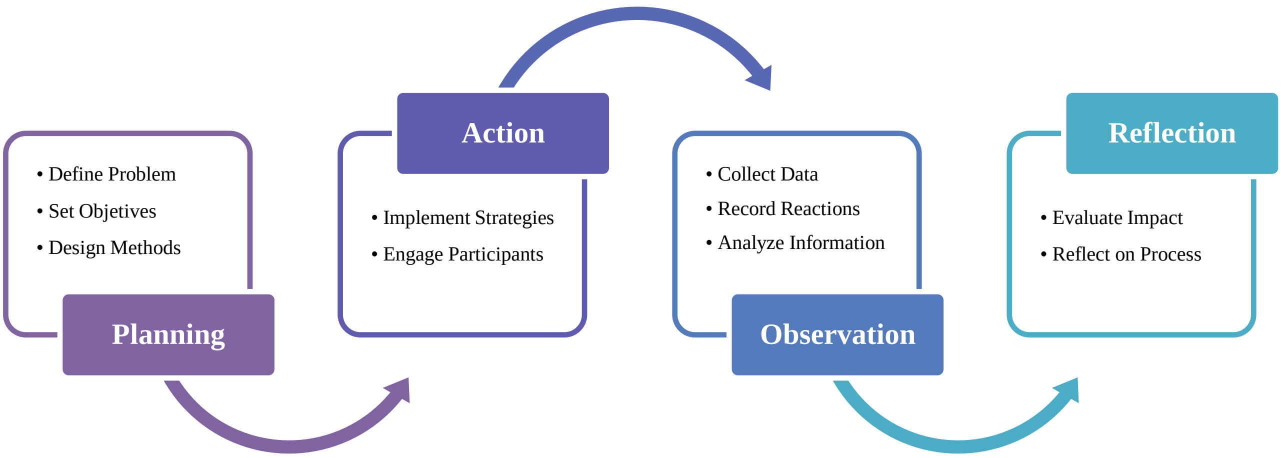

Figure 1. Diagram of the Methodological Procedure in Action Research

4- Results

The study assessed the impact of a teaching strategy that integrates technology and musical concepts on the language development of children aged 3 to 6 years. The effectiveness of the implemented activities, as well as student participation and progress, was assessed through the collection and analysis of both quantitative and qualitative data. Below are the most relevant findings, which provide a detailed overview of the intervention's effects on motivation, linguistic performance, and overall interest in learning.

4-1- Educational Interventions

The interventions addressed gaps in foundational musical concepts while fostering cognitive, practical, and affective engagement with music education. Structured activities, innovative methodologies, and continuous evaluation created a dynamic and interactive learning environment. This section outlines the components of the interventions, beginning with a diagnostic test to assess baseline knowledge and guide the personalization of teaching strategies. The diagnostic test results served as a benchmark for designing targeted pedagogical approaches to improve students' competencies. The following subsections detail the dimensions and subcategories of the interventions, illustrating the comprehensive approach taken to achieve the study's objectives.

4-2- Diagnostic Test

The pre-test was administered to assess students' prior knowledge of fundamental musical concepts before the intervention. This initial evaluation identified existing skills and competencies, enabling the customization of teaching activities to meet individual needs. Additionally, the pre-test provided a baseline for measuring progress throughout the study, allowing for an objective comparison of knowledge before and after the intervention. Table 1 outlines the dimensions and subcategories evaluated in the research.

Table 1. Dimensions and Subcategories of Research

Dimensions	Subcategories
Discrimination of sound qualities	Producing loud and soft sounds using a musical instrument.
Recognition of musical instruments	Identifying and naming wind, percussion, and string instruments.
The intonation of musical notes	Intoning the notes of the C Major scale in the correct order.
Recognition of the Staff and Treble Clef	Identifying and naming the Staff and Treble Clef using images.
Visual Recognition of musical figures	Naming and identifying whole, half, quarter, and eighth notes and rests.

4-3- Didactic Strategy

Following the diagnostic test, the teaching strategies were implemented, beginning with the introduction of generative artificial intelligence (AI) as a tool for inclusive musical learning. Data was collected throughout the intervention, and the results are presented below. Figure 2 presents a timeline illustrating the sequence of musical learning intervention, detailing the stages and activities implemented throughout the study. To relate the didactic strategy and the timeline of the musical learning intervention sequence, we can propose a mathematical model that captures the relationship between the intervention activities (independent variables) and the learning outcomes (dependent variables). The learning outcome L can be modeled in Equation 1:

$$L = \beta_0 + \beta_1 \sum_{i=1}^{8}(Ai * Ti) + \beta_2 \sum_{i=1}^{8}(Ai * Ei) + \beta_3 C + \in \tag{1}$$

where: Intervention Activities (Ai): Each week's activity (string instruments, wind instruments) contributes to the learning outcome. $\beta_o, \beta_1, \beta_2, \beta_3$, show coefficients representing the impact of each factor. Time Spent (Ti): The duration of each activity influences the learning outcome. Tool Effectiveness (Ei): The effectiveness of the tools used (Genially, Educaplay) enhances the impact of the activities. Control Group Factor (C) accounts for differences between the experimental and control groups. Error Term (ϵ) Represents unobserved factors affecting the learning outcome. For the experimental group, C=1, the effectiveness of tools like Genially and Educaplay (Ei) is maximized. For the control group, C = 0 and traditional methods are used, reflecting the effectiveness of non-digital tools (physical instruments, drawings).

This equation provides a framework for quantifying the impact of the didactic strategy and intervention timeline on learning outcomes, enabling statistical analysis of the results presented in Table 2.

Table 2. Descriptive Statistics of Pre-Test Results

Dimensions	Media	Standard Dev.
Discrimination of sound qualities	5	0.0
Recognition of musical instruments	4.4	1.5
The intonation of musical notes of the C Major scale	3.7	1.7
Recognition of the Staff and the Treble Clef	3.8	1.5
Visual Recognition of musical figures	3.8	1.6

Figure 2 presents a syllabus for a music course divided into eight weeks. Each week covers a specific topic related to music theory and practice. The weekly content is as follows:

Week 1: String Instruments – Fuchsia color, with a string instrument icon.

Week 2: Wind Instruments – Purple color, with a wind instrument icon.

Week 3: Percussion Instruments – Dark blue color, with a drum icon.

Week 4: The Staff and Treble Clef – Blue color, with a treble clef icon.

Week 5: Musical Figures – Turquoise color, with a musical note icon.

Week 6: Rhythm and Vocalization – Light blue color, with a voice icon.

Week 7: The C Major Scale – Green color, with a keyboard or notes icon.

Week 8: Sound Qualities – Light green color, with a musical note icon.

Figure 2. **Chronology of the Musical Learning Intervention Sequence**

Week 1: String Instruments

Experimental Group:

In the first session, students were introduced to Genially, a virtual tool designed for interactive musical learning. The teacher provided a detailed explanation of how to access and navigate the platform, highlighting its key features. As it was the students' first encounter with this tool, the session included a guided exploration of its basic functions. The teacher demonstrated how to use Genially to create musical activities, offering step-by-step instructions. During the lesson on string instruments, students were expected to read and analyze the presented concepts. Although they could name and describe how some instruments are played, the session revealed that many still needed to develop a deeper understanding of the string family.

Figure 3 illustrates students interacting with illustrative images and real instruments, thereby reinforcing both visual recognition and practical familiarity with string instruments.

Figure 3. **Learning stringed musical instruments through pictures**

In Figure 4, students are shown watching a video about string instruments. After two viewings, they were asked to recall and name at least three instruments. They then engaged with an interactive game on Genially via their mobile devices. The figure includes screenshots of both the video and the quiz.

Control Group:

Students began by viewing illustrations of 10 string instruments, accompanied by the teacher's detailed explanations. Additionally, they had the opportunity to observe and handle real instruments such as a guitar, violin, and piano, which helped reinforce their understanding. Each student was encouraged to recall and verbalize the instrument names, promoting oral expression and memory.

Figure 4. Using generative AI for learning wind instruments

Week 2: Wind Instruments

Experimental Group:

The session began with a video titled Wind Instruments, introducing the names, characteristics, and sounds of this instrument family. As seen in Figure 4, the video was replayed with pauses to foster group discussion and identification of each instrument. Students then completed an interactive story-based quiz on Genially using tablets and smartphones. This digital approach promoted active engagement, allowing students to identify and understand how wind instruments are played.

Control Group:

The lesson began with drawings of ten wind instruments paired with the teacher's explanation. Students also had the opportunity to observe a flute and a clarinet in person. Afterward, each child repeated the names of the instruments they remembered. The session concluded with an evaluation activity where students shared three wind instrument names with their peers.

Figure 5 illustrates their participation, showing students interacting with visuals and real instruments to consolidate their understanding.

Figure 5. Learning wind musical instruments through images

Week 3: Percussion Instruments

Experimental Group:

Students watched an educational video on percussion instruments twice, pausing to identify key elements. They then completed an interactive quiz on Genially, using digital devices to identify at least three instruments. This activity enhanced motivation and reinforced learning.

Figure 6 shows students watching the video and playing the interactive game, both of which facilitated knowledge retention and engagement.

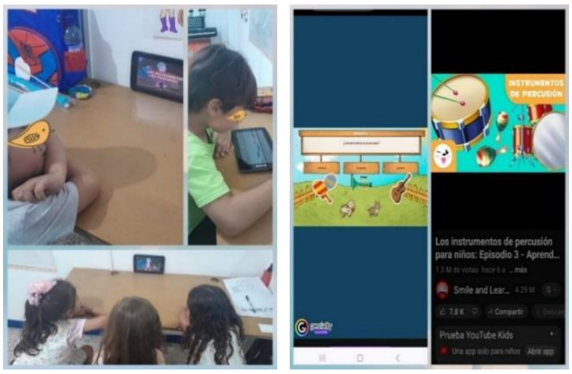

Figure 6. **Using generative AI for learning percussion musical instruments**

Control Group:

The session involved viewing illustrated percussion instruments, followed by a hands-on experience with a tambourine, xylophone, and maracas. Students then shared and named the instruments they remembered.

As shown in Figure 7, the combination of images and real instrument interaction helped dynamically reinforce the content.

Figure 7. **Learning percussion musical instruments**

Week 4: The Staff and the Treble Clef

Experimental Group:

Students watched an animated video on the pentagram and treble clef. They then participated in a group discussion, correctly identifying each element. Using mobile phones, they played a memory game on Educaplay to reinforce learning.

Figure 8. **Using generative AI to learn the Pentagram and the Treble Clef**

Figure 8 shows these digital resources, while Figure 9 displays students drawing the treble clef on paper and the classroom board, promoting visual memory and motor skills.

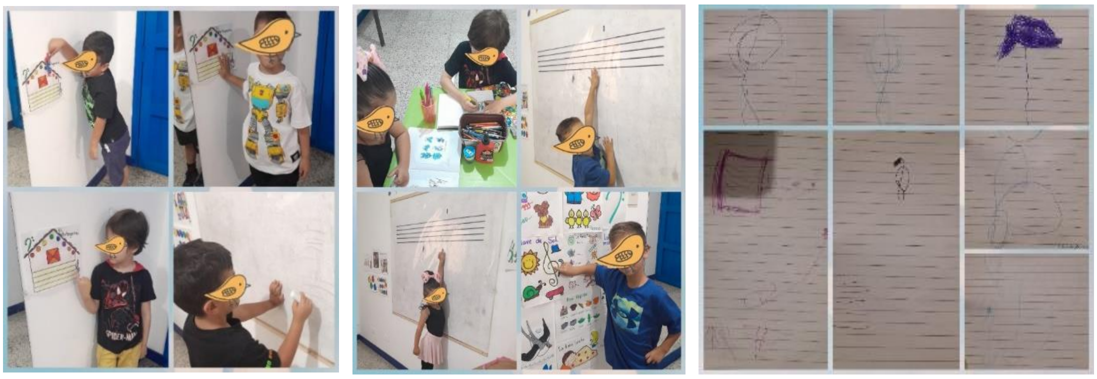

Figure 9. Learning the Pentagram and the Treble Clef through images and drawings

Week 5: Musical Figures

Experimental Group:

Students watched a video explaining musical figures such as whole, half, quarter, and eighth notes, along with their corresponding rests. They then discussed the content as a group and used digital quizzes on Genially and Wordwall for review.

Figure 10 shows the digital tools used for reinforcement and evaluation.

Figure 10. Using generative AI for learning musical figures

Control Group:

The class focused on drawing musical figures, supported by the teacher's explanations. Students identified the figures aloud and then played a card-based game to reinforce their knowledge.

Figure 11 illustrates their participation using drawings and interactive card activities.

Figure 11. Learning musical figures through drawings and cards

Week 6: Rhythm and Vocalization

Experimental Group:

Students watched an interactive video titled I Have a Dog, which taught rhythm through clapping and vocalization. They repeated the exercise and then practiced autonomously. A digital roulette game on Wordwall was used for evaluation.

Figure 12 includes screenshots of the video and the game, showing high engagement.

Figure 12. **Using generative AI to learn a rhythm and language exercise**

Control Group:

Using images and teacher guidance, students clapped along with the words of the I Have a Dog exercise. They later performed the routine individually.

Figure 13 presents their group and individual practice, reinforcing rhythm through voice and movement.

Figure 13. **Learning rhythmic exercises through drawings and clapping**

Week 7: The C Major Scale

Experimental Group:

Students watched a video introducing the C Major scale, followed by group and individual singing exercises that focused on note intervals. They also played a virtual piano app to reinforce pitch recognition.

Figure 14 shows children using xylophones and digital tools to sing and play scale notes.

Figure 14. **Using generative AI to learn musical notes in the C Major scale**

Control Group:

Students sang along with the teacher using colored circles to represent each note. They then jumped on floor circles labeled with notes and played the scale on a xylophone.

Figure 15 illustrates their multisensory learning experience, which combines visual, auditory, and kinesthetic strategies.

Figure 15. **Learning musical notes and the C Major scale.**

Week 8: Sound Qualities

Experimental Group:

Students learned about pitch by watching the "The Piano" video and practicing high and low sounds with their voices. They then used a digital piano to further explore these sounds.

Figure 16 displays screenshots of the video and interactive Genially game, supporting the understanding of pitch.

Figure 16. **Using generative AI to learn sound qualities such as intensity and pitch**

Control Group:

Children explored pitch using voice and guitar sounds, supported by a visual analogy of a tree (representing high pitch) and a flower (representing low pitch). They later used classroom instruments, such as the xylophone and piano, for reinforcement.

Figure 17 presents the activity and the use of visual aids and real instruments for practical learning.

Figure 17. **Post-test presentation with experimental group and control group**

Post-Test:

At the end of week eight, a post-test was administered to assess students' understanding and pronunciation across all covered topics.

The results of the descriptive statistics of the pre-test in Table 2 reflect the children's initial level of musical knowledge and skills in the dimensions assessed:

1) Discrimination of sound qualities (M = 5.0, SD = 0.0): shows perfect and uniform performance in the discrimination of sound qualities. All participants correctly identified high and low sounds, suggesting that this ability is well-developed in the group and does not present variability.
2) Recognition of musical instruments (M = 4.4, SD = 1.5): The mean indicates a solid level of recognition of musical instruments, although the standard deviation evidences some scatter in the results. This result suggests that some children excel in this area, while others may need reinforcement.
3) The intonation of musical notes (C Major) (M = 3.7, SD = 1.7): This dimension shows the lowest mean and the most significant variability. The data indicate that children have difficulty intoning musical notes correctly, representing a key area for intervention and improvement.
4) Recognition of the Staff and the Treble Clef (M = 3.8, SD = 1.5): Performance on this dimension is moderate, with some children achieving solid recognition while others show less understanding. This outcome reflects a basic initial understanding of these musical concepts.
5) Visual recognition of musical figures (M = 3.8, SD = 1.6): Similar to the previous dimension, the results indicate a moderate level with considerable variability. Some children recognize musical figures well, but others may need additional activities to consolidate this knowledge.

Thus, the Discrimination of sound qualities dimension is the most solid and uniform among participants, while The intonation of musical notes (C Major) represents the 1)most significant challenge, with lower performance and more dispersed results. This outcome suggests the need for specific activities, such as intonation exercises and instrument practice, to strengthen skills in these less-developed areas.

4-4- Statistical Analysis

Quantitative data from pre- and post-tests revealed the following: Pre-test findings showed that both groups demonstrated moderate proficiency in musical concepts, with notable variability in intonation and visual recognition of musical figures.

Post-test Findings: The experimental group demonstrated higher motivation and engagement, which can be attributed to the interactive and personalized nature of ICT-based activities.

Statistical tests (e.g., Shapiro-Wilk and Mann-Whitney U) confirmed that while both instructional approaches were practical, the ICT-mediated methodology fostered tremendous enthusiasm and participation among children. The dataset with the data is available for replication in the Mendeley open repository [30].

The results indicate that the students did not face significant difficulties in discriminating sound qualities or recognizing musical instruments, suggesting a high level of homogeneity among the participants. However, the intonation of musical notes in the C Major scale emerged as an area of concern, with the lowest mean score (3.7) and the highest variability (SD = 1.7). This study highlights a clear opportunity to strengthen this particular skill.

Similarly, other dimensions—such as the recognition of musical instruments, the staff and treble clef, and the visual identification of musical figures—yielded moderate mean scores ranging from 3.8 to 4.4, with standard deviations between 1.5 and 1.6. These results indicate some variability and dispersion in performance across these areas.

Notably, the data reveal limited mastery in two key areas: intonation skills and the visual recognition of musical figures and the staff. A Shapiro-Wilk normality test was conducted to further analyze the data distribution, with the results presented in Table 3.

Table 3. Shapiro-W normality tests

		Statistical W	Sig.
Pre-test	Control	0.882995	0.240076
	Experimental	0.732794	0.008359
Pos-Test	Control	0.813590	0.055675
	Experimental	0.884268	0.246076

The Shapiro-Wilk normality test indicates that in the Pre-test, the Control group presents data with a normal distribution ($p = 0.240$), while the Experimental group does not meet this condition ($p = 0.008$). On the other hand, in the Post-test, both groups (Control and Experimental) show significance values greater than 0.05 ($p = 0.056$ and $p = 0.246$, respectively), suggesting that the data follow a normal distribution. These results are essential to determine the choice of statistical tests, and it is necessary to opt for non-parametric tests in the pre-test of the experimental group due to the lack of normality. Therefore, we have decided to apply a Mann-Whitney U test.

Figure 18 shows the Statistical W (blue bars) and Significance (Sig.) values (orange line) for the Control and Experimental groups at the pre-test and post-test stages.

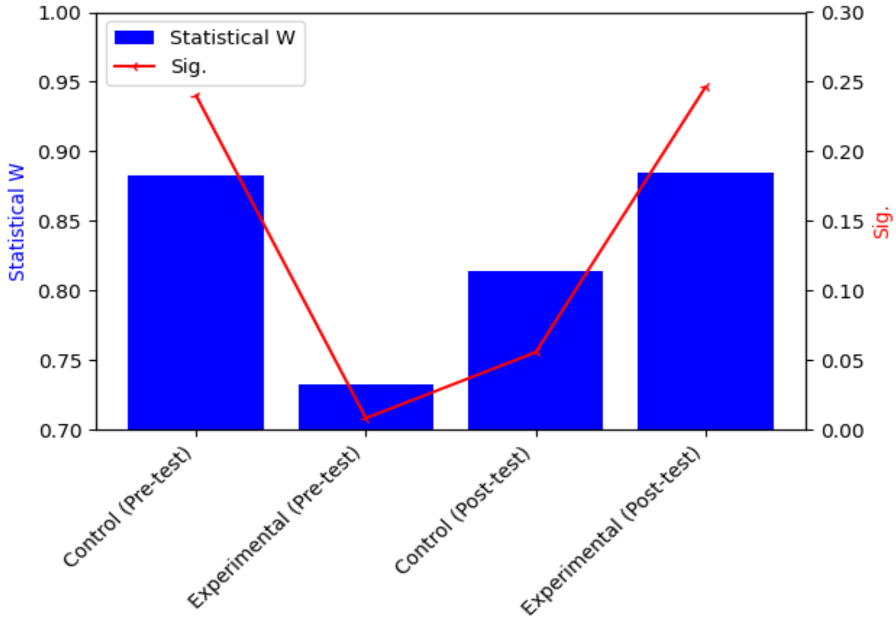

Figure 18. **Comparison of Statistical W and Significance (Sig.) Values in Pre-Test and Post-Test for Control and Experimental Groups**

Values for both groups are generally close to 1, indicating that the data do not deviate significantly from a normal distribution. In the pre-test, the experimental group showed a lower value (0.7328) compared to the control group (0.8830), indicating a more significant deviation from normality in the experimental group.

In the post-test, the values of both groups are closer (Control: 0.8136, Experimental: 0.8843), showing less variability between them. Significance values (p-value) determine whether the data are typically distributed.

In the pre-test, the Control group has a p-value of 0.2401 (>0.05), indicating that the data are not significantly different from a normal distribution. In contrast, the Experimental group has a p-value of 0.0084 (<0.05), suggesting a significant deviation from normality.

In the post-test, both groups have p-values greater than 0.05 (Control: 0.0557, Experimental: 0.2461), indicating that the data are consistent with a normal distribution at this stage.

The experimental group exhibits a more significant deviation from normality in the pre-test but shows a significant improvement in the post-test, reaching values comparable to those of the control group. This study may reflect a positive effect of the intervention, as evidenced by the normalization of the data in the Experimental group at the post-test.

Table 4. **Mann-Whitney U Test**

	Statistic U	p Value
Pre-test	22.5	0.7947
Pos-Test	17.5	0.3625

As shown in Table 4, the results of the Mann-Whitney U test for both the pre-test and post-test reveal no significant differences between the Control group (which utilized concrete materials) and the Experimental group (which employed ICTs). In both cases, the p-values exceeded 0.05 (0.7947 for the pre-test and 0.3625 for the post-test), leading to the retention of the null hypothesis (H_0). This study suggests that the type of material used—concrete or digital—did not significantly influence the outcomes at either evaluation stage.

In conclusion, concrete materials and information and communication technologies (ICTs) proved effective in supporting the musical teaching-learning process, each offering unique benefits. These findings highlight the versatility of both approaches in enhancing musical education.

5- Discussion

Integrating generative artificial intelligence (AI) in education has demonstrated significant potential to enhance learning across various domains, including music, particularly in inclusive contexts [31]. This study focused on the application of AI in musical learning [32] for preschool children, emphasizing its impact on language development and the acquisition of musical skills. The findings align with prior research, underscoring the value of educational technology, specifically AI, as a tool for personalizing learning and fostering inclusion for students with diverse abilities. This discussion examines the most relevant findings of the study, focusing on personalized learning, gamification, educational inclusion, implications for educator training, and the potential of generative AI in child development. These themes reflect the transformative impact of AI on children's learning and highlight opportunities for future research.

5-1- Personalization of Learning Through AI

Generative AI has proven effective in personalizing learning experiences by adapting to the unique needs of each student. Consistent with previous studies, personalization has been shown to enhance student motivation and engagement. In our study, interactive ICT tools powered by AI, such as Genially and Educaplay, created a dynamic and tailored learning environment. These tools significantly improved children's motivation and facilitated the development of musical and linguistic skills, demonstrating the potential of AI to cater to individual learning styles and paces.

Therefore, several studies have demonstrated that attention processes, working memory, and cognitive flexibility undergo rapid development between the ages of 4 and 7, which may enhance the effectiveness of educational interventions during this critical period [33].

Generative AI has demonstrated its effectiveness in personalizing learning experiences [34] by adapting to the specific needs of each student. Consistent with previous research, personalization enhances student motivation and engagement. In our study, AI-powered interactive ICT tools—such as Genially and Educaplay—fostered a dynamic and tailored learning environment. The integration of these tools not only significantly increased children's motivation but also facilitated the development of both musical and linguistic skills, highlighting AI’s potential to accommodate diverse learning styles and paces. Notably, the educational content incorporated features such as interactive questioning, virtual assistants, and adaptive materials that provided immediate, real-time feedback.

5-2- Gamification and Interactivity in Musical Learning

Gamification powered by artificial intelligence (AI) plays a crucial role [35] in maintaining children's interest and facilitating the understanding of abstract concepts. In line with previous research, our findings demonstrate that AI-driven gamified activities effectively capture children's attention and promote learning through repetition and active participation. This approach not only supported the acquisition of complex musical concepts, such as instrument identification but also enhanced pronunciation and intonation skills, demonstrating the versatility of AI in educational settings. Moreover, gamification serves as an inclusive tool by allowing students with varying levels of musical ability to progress at their own pace. In this regard, designing interactive activities that accommodate different learning styles (auditory, visual, and kinesthetic) is essential to creating a musically meaningful and accessible learning environment for all students [36].

5-3- Inclusion of Children with Diverse Needs

A key strength of AI in education is its ability to support inclusive learning environments for children with disabilities or special educational needs. Research confirms that AI fosters greater inclusion and personalization. In our study, interactive musical activities enabled all children to participate actively, regardless of their initial abilities. Interactive devices also boosted engagement and self-confidence, highlighting AI's potential to create equitable learning opportunities for diverse learners.

5-4- Limitations and Recommendations for Future Research

While the results of this study are promising, certain limitations must be acknowledged, including the small sample size and the single-institution context. Future research should involve more extensive and diverse samples across multiple educational settings. Additionally, longitudinal studies are necessary to evaluate the long-term effects of generative AI on children's musical and linguistic development, thereby ensuring the sustainability and effectiveness of these technologies over time.

5-5- The Role of the Teacher in the Integration of Generative AI

The successful integration of AI in education heavily depends on teacher training and adaptability. As emphasized by Ayeni et al. [31], continuous professional development is crucial for educators to leverage the potential of digital tools fully. In this study, teacher training using AI-driven platforms was critical to the intervention's success. Future research should explore how educator preparedness influences the implementation of AI and its impact on learning outcomes.

5-6- The Potential of Generative AI in Child Development

Generative AI, when effectively integrated into education, has a profound positive impact on children's language and musical skill development. Beyond individualizing learning, AI creates inclusive and participatory environments that encourage active student engagement. However, further research is needed to optimize the implementation and evaluation of these tools, ensuring they are accessible and effective for all students, regardless of their initial abilities or backgrounds.

6- Conclusions

The study demonstrated that integrating generative artificial intelligence (AI) into inclusive musical learning for preschool children has a positive impact on the development of both musical and linguistic skills. The findings support the hypothesis that technology, particularly artificial intelligence (AI), can be a powerful tool to enhance learning by facilitating the acquisition of musical concepts and improving pronunciation. ICT tools, such as Genially, Educaplay, and Wordwall, have successfully created a dynamic, motivating, and adaptive learning environment tailored to students' needs. However, the study also revealed certain limitations, such as the small sample size and the short duration of the intervention, which highlight the need for further research to explore the long-term effects of these technologies. Below, the main conclusions are outlined.

Generative AI has emerged as a key factor in fostering musical and linguistic development in preschool children. The active interaction enabled by technological tools, such as Genially and Educaplay, significantly improved children's ability to identify musical instruments, enhance pronunciation, and retain key concepts. These tools provided a multimodal learning experience, combining visual and auditory elements to make abstract concepts more accessible and engaging.

Combining digital tools and hands-on interaction with physical instruments, such as the recorder, enriched the learning experience. This approach allowed children to explore the physical and sound characteristics of instruments, reinforcing theoretical knowledge through practical application. Integrating visual resources and direct interaction fostered curiosity, participation, and a deeper understanding of musical concepts.

The implementation of pre-test and post-test assessments provided a clear comparison of children's knowledge before and after the intervention. Using representative images of musical concepts, the study measured children's ability to identify and name these concepts, revealing significant improvements in pronunciation and understanding. The experimental group, which interacted with ICT tools and generative AI, showed particularly notable progress, underscoring the effectiveness of these technologies in enhancing learning outcomes.

The study highlights the importance of training preschool teachers using interactive musical technologies, including generative artificial intelligence (AI). The effective integration of these tools supports musical concept learning and strengthens essential linguistic skills, thereby contributing to children's holistic development. Continuous professional development for educators is crucial to maximizing the potential of digital tools and ensuring their successful implementation in the classroom.

Despite its promising results, the study has several limitations, including a small sample size and a short intervention duration. These constraints highlight the need for further research to validate the findings and investigate the long-term effects of generative AI on musical and linguistic learning.

6-1- Future Work

Conduct studies with more extensive and more diverse samples to validate the findings across different educational contexts and populations. Implement long-term evaluations to assess the sustained impact of generative AI on children's musical and linguistic development. Investigate the effectiveness of AI-driven tools for children with special educational needs, such as hearing or language impairments. Develop and evaluate training programs for educators to enhance their proficiency in using AI and digital tools in the classroom. Explore the potential of hybrid learning environments that combine AI-driven platforms with traditional teaching methods to optimize learning outcomes. Create innovative, AI-based educational resources that cater to diverse learning styles and needs, ensuring accessibility and inclusivity. By addressing these areas, future research can further harness the potential of generative AI to transform early childhood education, making it more engaging, inclusive, and effective.

7- Declarations

7-1- Author Contributions

Conceptualization, P.A.-V., M.R.-C., M.Ch.-C., and J.J.-G.; methodology, P.A.-V., M.R.-C., M.Ch.-C., and J.J.-G.; software, P.A.-V.; validation, P.A.-V., M.Ch.-C., and J.J.-G.; formal analysis, P.A.-V., M.R.-C., M.Ch.-C., and J.J.-G.; investigation, P.A.-V., M.R.-C., M.Ch.-C., and J.J.-G.; resources, P.A.-V.; data curation, P.A.-V. and L.S.-U.; writing—original draft preparation, P.A.-V., M.R.-C., M.Ch.-C., L.S.-U., and J.J.-G.; writing—review and editing, P.A.-V., M. R.-C., M.Ch.-C., L.S.-U., and J.J.-G.; visualization, P.A.-V. and J.J.-G.; supervision, P.A.-V. and J.J.-G.; project administration, P.A.-V.; funding acquisition, P.A.-V. All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

The data presented in this study are available at https://doi.org/10.17632/2kyksx8hty.2.

7-3- Funding

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7-4- Institutional Review Board Statement

The research was conducted using non-invasive methods that posed no risk to participants, and therefore, formal approval from a research ethics committee was not required. All participants were informed about the study's purpose, and their participation was voluntary. The confidentiality and anonymity of the collected data were strictly maintained throughout the study.

7-5- Informed Consent Statement

All participants were fully informed about the study's objectives and voluntarily agreed to participate in the study.

7-6- Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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