Federal University of Rio Grande do Norte
Center of Technology
Graduate Program in Electrical and Computer Engineering

Musicalization with Educational Robotics

José Lindenberg de Andrade

Advisor: Luiz Marcos Garcia Gonçalves, Ph.D.

Co-advisor: Pablo Javier Alsina, Ph.D.

Master's Thesis submitted to the Graduate Program in Electrical and Computer Engineering at UFRN (Area of Concentration: Computer Engineering) as part of the requirements for obtaining the degree of Master of Science.

PPgEEC order number: 701
Natal, RN, December 2025

Universidade Federal do Rio Grande do Norte - UFRN
Sistema de Bibliotecas - SISBI
Catalogação de Publicação na Fonte. UFRN - Biblioteca Central Zila Mamede

Andrade, Jose Lindenberg de.
Musicalization with educational robotics / Jose Lindenberg de Andrade. - 2026.
100 f.: il.

Dissertação (mestrado) - Universidade Federal do Rio Grande do Norte, Centro de Tecnologia, Programa de Pós-Graduação em Engenharia Elétrica e de Computação, Natal, RN, 2026.
Orientação: Prof. Dr. Luiz Marcos Garcia Gonçalves.
Coorientação: Prof. Dr. Pablo Javier Alsina.

1. Educational robotics - Dissertação. 2. Musicalization - Dissertação. 3. Music education - Dissertação. 4. BNCC - Dissertação. 5. EcoMusic - Dissertação. I. Gonçalves, Luiz Marcos Garcia. II. Alsina, Pablo Javier. III. Título.

RN/UF/BCZM CDU 004.896

Elaborado por Jackeline dos Santos Pinheiro da Silva Maia Cavalcanti - CRB-15/317

To my beloved God, to my parents, and to my friends, for being the safe harbor in my life.

Acknowledgment

To my advisor, Ph.D. Luiz Marcos, and my co-advisor, Ph.D. Pablo Alsina, I am grateful for their professionalism and guidance.

To Professor Ph.D. Márcio Valério de Araújo, for his support since the beginning of the research for this work, which originated from my undergraduate thesis.

To the panel members, Professor Ph.D. Carla Curvelo and Professor Ph.D. Anderson Souza, for accepting the invitation and for their contributions.

To all my colleagues at the Educational Robotics Laboratory for their friendship and camaraderie throughout my graduate studies.

To the other graduate colleagues, for their critiques and suggestions.

To my parents, Florentino and Maria Luiza, my family and friends, for their support during this journey.

Abstract

The integration of music and educational robotics remains underexplored, even though both areas offer strong potential to promote active, interdisciplinary, and meaningful learning. This work investigates how musicalization can be incorporated into robotics to enhance student engagement and support the practical understanding of musical, electronic, and computational concepts. To this end, the study proposes EcoMusic, an ecological musical device built from electronic components and recycled materials, programmed to play melodies through interactive buttons. The research is grounded in the competencies of Brazil's National Common Curriculum (BNCC) and in theoretical foundations from music education, robotics, sustainability, and creative learning. The study was conducted with prior authorization from the Research Ethics Committee of the Federal University of Rio Grande do Norte (UFRN), ensuring compliance with ethical standards for research involving human participants. EcoMusic was implemented in a public school with 25 students aged 11 to 17, over two instructional sessions that introduced concepts of sound and frequency, programming, device assembly, and musical experimentation. Data collection involved questionnaires administered to both students and the classroom teacher. Results indicate that integrating musicalization into robotics increases motivation, stimulates curiosity, facilitates understanding of musical concepts, and strengthens skills such as collaboration, creativity, and logical thinking. The use of recycled materials also encouraged reflections on sustainability and conscious consumption. The findings demonstrate that EcoMusic is an accessible, interdisciplinary, and curriculum-aligned pedagogical tool that expands opportunities for active experiences in music and technology within basic education.

Keywords: Educational Robotics; Musicalization; Music Education; BNCC; EcoMusic.

Resumo

A integração entre música e robótica educacional permanece pouco explorada, embora ambas as áreas apresentem forte potencial para promover uma aprendizagem ativa, interdisciplinar e significativa. Este trabalho investiga como a musicalização pode ser incorporada à robótica com o objetivo de ampliar o engajamento dos estudantes e apoiar a compreensão prática de conceitos musicais, eletrônicos e computacionais. Nesse sentido, o estudo propõe o EcoMusic, um dispositivo musical ecológico construído a partir de componentes eletrônicos e materiais reciclados, programado para executar melodias por meio de botões interativos. A pesquisa fundamenta-se nas competências da Base Nacional Comum Curricular (BNCC) e em referenciais teóricos da educação musical, da robótica, da sustentabilidade e da aprendizagem criativa. O estudo foi realizado com autorização prévia do Comitê de Ética em Pesquisa da Universidade Federal do Rio Grande do Norte (UFRN), assegurando a conformidade com os princípios éticos aplicáveis a pesquisas envolvendo seres humanos. O EcoMusic foi implementado em uma escola pública com 25 estudantes, com idades entre 11 e 17 anos, ao longo de duas sessões instrucionais que abordaram conceitos de som e frequência, programação, montagem do dispositivo e experimentação musical. A coleta de dados envolveu a aplicação de questionários aos estudantes e ao professor responsável pela turma. Os resultados indicam que a integração da musicalização à robótica aumenta a motivação, estimula a curiosidade, facilita a compreensão de conceitos musicais e fortalece habilidades como colaboração, criatividade e raciocínio lógico. O uso de materiais reciclados também favoreceu reflexões sobre sustentabilidade e consumo consciente. Os achados demonstram que o EcoMusic constitui uma ferramenta pedagógica acessível, interdisciplinar e alinhada ao currículo, ampliando as possibilidades de experiências ativas em música e tecnologia na educação básica.

Keywords: Robótica Educacional; Musicalização; Educação Musical; BNCC; EcoMusic.

Contents

List of Figures

List of Tables

List of Abbreviations

AI Artificial Intelligence

ASD Autism Spectrum Disorder

BNCC Base Nacional Comum Curricular

CAAE Certificate of Presentation for Ethical Consideration

DSR Design Science Research

EDA Electrodermal Activity

ER Educational Robotics

Hz Hertz

PCB Printed Circuit Board

PPgEEC Graduate Program in Electrical and Computer Engineering

REC Research Ethics Committee

STEAM Science, Technology, Engineering, Arts, and Mathematics

UFRN Federal University of Rio Grande do Norte

Chapter 1

Introduction

Educational Robotics (ER) has expanded significantly since the 1960s and is now present in a wide range of educational contexts, enabling students to explore technological concepts through hands-on experimentation and creative problem-solving (Papert 1994). Current robotic kits offer diverse levels of complexity—ranging from block-based systems to programmable microcontrollers, often integrating sensors, actuators, visual interfaces, and even sound components (Andrade 2023). These technologies support the development of logical reasoning, creativity, mathematical understanding, and technological fluency, consolidating ER as an important pedagogical resource for 21st-century education (Machado et al. 2024).

Among the various learning opportunities provided by educational robotics, sound and music have gained visibility as complementary elements capable of enriching the learning experience. Kits such as Makey Makey™, LEGO SPIKE Prime™, and Arduino-based musical devices allow students to experiment with rhythm, melody, and sound synthesis while engaging with programming and electronics (Andrade et al. 2024). However, despite these possibilities, the relationship between robotics and music remains underexplored, particularly when considering the pedagogical approach of musicalization, which is a process focused on exploratory, sensory, and creative experiences with sound (Hallam 2010). Musicalization emphasizes exploratory, sensory, and constructive forms of musical understanding. Early cognitive studies show that students create their own representational strategies to make sense of simple rhythms, revealing the importance of hands-on approaches to musical learning (Bamberger 1975).

Music education is known to stimulate cognitive, emotional, and social development, contributing to improvements in memory, concentration, motor coordination, and creative expression (Hodges 2019). However, traditional teaching methods often rely on theoretical abstractions or repetitive exercises, limiting student engagement and distancing musical learning from a more active and meaningful experience. Integrating musicalization into robotics may help overcome these challenges by combining technological experimentation with artistic creation, resulting in more dynamic, interactive, and engaging learning environments (Andrade et al. 2024).

Within this context, this Master's dissertation work proposes EcoMusic that emerges as a pedagogical approach that unites robotics, music, sustainability, and programming. Designed using low-cost electronic components and recyclable materials, EcoMusic functions as an interactive musical device capable of playing programmed melodies (Andrade et al. 2024). Its design promotes interdisciplinary learning by connecting environmental awareness, technological construction, and musical creation. Furthermore, its structure aligns with the competencies and skills established by the Brazilian National Common Curriculum (BNCC), strengthening its relevance for contemporary educational practices.

Despite the well-documented benefits of music education on cognitive and socio-emotional development (Hallam 2010, Hodges 2019) and the growing use of educational robotics to promote active learning (Benitti 2012), empirical studies examining the integration of musicalization into educational robotics remain scarce. This dissertation addresses this gap by investigating whether the EcoMusic device can make music education more attractive, meaningful, and accessible, especially in public school contexts with limited resources.

Our study evaluates the implementation of EcoMusic in a real classroom setting, examining the perceptions, behaviors, and learning experiences of the students and the teacher. By analyzing practical activities, questionnaires, and teacher feedback, the research seeks to understand how the convergence of music and robotics can foster creativity, motivation, technological understanding, and broader artistic expression (Andrade et al. 2024). Thus, this work frames EcoMusic not only as a technological tool, but also as an interdisciplinary educational model that responds to contemporary challenges and contributes to more inclusive and engaging practices in basic education.

1.1 Justification

Educational robotics is widely recognized for promoting skills and abilities relevant to contemporary education, including critical thinking, creativity, problem-solving, and collaboration. However, robotics alone, depending on the context, does not guaranty pedagogical depth. Approaches that integrate sensory, artistic, and expressive dimensions can significantly expand their learning potential.

Musicalization stands out in this regard. Music stimulates multiple cognitive and socio-emotional processes, enhancing logical reasoning, memory, attention, and creativity (Hallam 2010). However, its integration with robotics remains underexplored, representing an important gap in research and pedagogical practice. EcoMusic addresses this gap by combining sustainability, technology, and music in a hands-on learning experience that encourages exploration, construction, and sound experimentation. In addition, the project aligns with the BNCC guidelines by integrating competencies related to culture, digital technologies, experimentation, and artistic expression. This interdisciplinary articulation resonates with contemporary educational models such as STEAM (Science, Technology, Engineering, Arts, and Mathematics), which emphasize the integration of scientific and artistic domains to promote holistic learning (Yakman 2008). Regarding the growing emphasis on STEAM education and the need for environmentally conscious pedagogical models, EcoMusic presents a relevant and timely contribution.

Thus, this research is justified by the need to understand and evaluate the pedagogical impacts of musicalization integrated into educational robotics, particularly in terms of cognitive, socio-emotional, technological, and environmental competencies, contributing to a more inclusive, engaging, and meaningful learning experience. This research contributes by offering an innovative, sustainable, and interdisciplinary approach that strengthens both scientific and artistic dimensions of student learning, while addressing a recognized gap in the literature and in school practices.

1.2 Research Problem and Hypothesis

Although educational technologies have advanced, music education in schools still faces challenges related to student participation, motivation, and practical understanding of musical concepts. Traditional instructional approaches often emphasize abstract theory or repetitive technical practice, which can limit the interest of students and hinder meaningful learning experiences.

There is a growing need for pedagogical strategies that integrate different forms of expression, particularly music, technology, and robotics, to promote more relevant and interactive learning. EcoMusic, as a tool that integrates musicalization, programming, and electronics, represents a promising alternative. However, its actual pedagogical impact has not yet been systematically evaluated.

Hence, the central problem of this study is to determine whether the integration of musicalization with educational robotics, mediated by EcoMusic, can make music education more attractive, interactive, and effective for students. This includes examining whether such an approach:

- increases engagement;
- stimulates creativity;
- promotes active participation;

- fosters practical understanding of musical and technological concepts;
- aligns with BNCC competencies and skills.

Furthermore, the study seeks to determine whether the use of EcoMusic can overcome the limitations of traditional methodologies and contribute to a more interdisciplinary, contextualized, and meaningful musical learning experience.

This study works on the research hypothesis that the use of educational robotics as a mediating tool in musicalization can enrich music teaching by promoting interactive, engaging, and meaningful learning, while primarily supporting musical understanding and, in a complementary way, introducing technological concepts. In order to verify the hypothesis, a series of 4 steps to be followed were defined, as described in the following:

- Observe and measure EcoMusic's efficiency and effectiveness as an interdisciplinary tool integrating music, programming, and electronics.
- Analyze how musicalization affects student engagement, creativity, and participation during activities involving EcoMusic.
- Collect and evaluate perceptions and feedback from students and teachers regarding EcoMusic and its role in the learning process.
- Verify whether musicalization combined with educational robotics makes music education more meaningful, interactive, and aligned with BNCC guidelines.

1.3 Scope of the Study

This research was conducted in Brazil, at the Escola Municipal Josefa Botelho, located in the city of Natal, Rio Grande do Norte (RN), with a group of 25 students aged between 11 and 17 years. These participants are enrolled in the Brazilian Basic Education public system, specifically in the Elementary School Level I (which is for 11–14 years old children) and in the Elementary School Level II (for 15–17 years old children).

This study was approved by the Research Ethics Committee of the Januário Cicco Maternity School of the Federal University of Rio Grande do Norte (UFRN), under the Certificate of Presentation for Ethical Consideration (CAAE) number 87708925.6.0000.0253, with approval opinion number 7.700.639, issued on July 10, 2025.

The intervention occurred in two pedagogical sessions designed to progressively introduce and apply the concepts under investigation. The first session presented the fundamental principles of music education, programming, and educational robotics, establishing a conceptual and contextual foundation for the use of EcoMusic. The second session focused on the practical application of the EcoMusic device, during which students interacted with its musical and technological components, experimenting with sound generation, rhythm manipulation, and programmable features in a hands-on learning environment.

After the practical activities, data was collected through structured questionnaires administered to all participating students. These instruments captured students perceptions, engagement levels, and also their impressions about the integration of musicalization into robotics-based learning. In addition, a complementary questionnaire was administered to the classroom teacher, providing a pedagogical perspective that enriched the interpretative framework of the study.

Together, these data sources support a comprehensive analysis of the pedagogical effects of incorporating educational robotics into musicalization through the EcoMusic project, enabling the evaluation of its potential to enhance student engagement, creativity, and meaningful learning. These sessions in class and questionnaires will be further detailed, in Chapter 5.

1.3.1 Contribution of the Present Study

The main contribution of this work is towards verifying our central hypothesis, which is to determine the benefits and issues of the application of Educational Robotics in Musical Education. Hence, this work contributes to ongoing discussions on active learning and interdisciplinary methodologies in educational robotics, applied to Music. In addition to this central contribution that verifies our main hypothesis, other main innovative and relevant findings of this work include:

- **Empirical evidence from a real classroom context**, demonstrating that the integration of educational robotics into musicalization can positively influence student engagement, curiosity, and conceptual understanding, as observed through both quantitative and qualitative data;
- **Validation of a hands-on and interdisciplinary pedagogical approach**, in which musical concepts such as notes, frequencies, rhythm, and sound behavior are meaningfully explored through robotics and sound experimentation;
- **A replicable and adaptable instructional model**, grounded in short-duration classroom interventions and accessible technological resources, which can be implemented in diverse educational contexts and age groups with appropriate adjustments;
- **Learner-centered insights into engagement and learning differences**, revealing variations related to developmental stages and individual learning profiles, thereby informing the design of differentiated and inclusive robotics-based music activities;
- **Evidence of technology as a mediating tool rather than an end in itself**, highlighting how educational robotics can support conceptual learning, creativity, and interdisciplinary thinking when intentionally aligned with pedagogical goals.

By articulating empirical results with pedagogical reflection, the findings of this study are particularly relevant for educators, researchers, and policymakers seeking effective strategies to integrate music, technology, and sustainability into meaningful learning experiences.

1.4 Text Structure

This Master's dissertation is organized into the following chapters:

- **Chapter 1 – Introduction:** Presented the research context, justification, problem, hypothesis, and study structure.
- **Chapter 2 – Robotics and Music: Theoretical Integration:** Discusses theoretical foundations linking music, musicalization, and educational robotics.
- **Chapter 3 – Related Work:** Reviews initiatives and studies involving music and robotics, identifying contributions and research gaps.
- **Chapter 4 – Comparing Robotics Kits and EcoMusic:** Examines existing robotics kits and contrasts them with EcoMusic.
- **Chapter 5 – Problem and Proposed Solution:** Describes EcoMusic, its pedagogical foundations, its alignment with BNCC, and the technical procedures used.
- **Chapter 6 – Experiments and Results:** Reports the experiments conducted with EcoMusic and presents the corresponding analyses.
- **Chapter 7 – Conclusion:** Summarizes findings and outlines future research directions and expected contributions.

Chapter 2

Robotics and Music: Theoretical Integration

At the end of the 1960s, Seymour Papert introduced the concept of constructionist learning, suggesting that children learn better by creating tangible things, such as robots. He argues that robotics can help develop problem solving skills and critical thinking (Papert 1994). Robotics can be integrated into various disciplines to improve students' understanding in areas such as mathematics, science, and technology, promoting 21st-century skills like collaboration, communication, creativity, and critical thinking (Papert 1980). On its side, it is well known that the effects of music education in the school environment contribute to intellectual, social, and personal development, providing various benefits to the school environment (Blasco-Magraner et al. 2021). In this Chapter, we deal with the theories involved in the integration of robotics in music education.

2.1 Robotics in Music Education

The combination of robotics and music provides an innovative and rich interdisciplinary approach to education (Martinez-Roig et al. 2023). Although music can affect students cognitive and emotional development (Hodges 2019), new technologies, including robotics, can facilitate collaborative musical experiences, expanding the possibilities for music education (Weinberg & Driscoll 2006).

Among the works that integrate educational robotics with music, some specifically explore the design and development of robots capable of musical interaction with humans, which involve technical and creative challenges (Weinberg & Driscoll 2006).

when applied in educational robotics, musicalization is an approach that integrates musical elements into the teaching of robotics, making learning more engaging and multidisciplinary. By combining music and technology, students are encouraged to explore concepts of rhythm, melody, and harmony while the focus is on developing technical skills in programming and engineering. Robots can be programmed to play instruments, compose music, or respond to sound stimuli, providing a rich and dynamic learning experience (Mueller & Rohs 2020).

In contrast, musicalization with educational robotics fosters a collaborative and inclusive environment in which students with diverse interests can contribute meaningfully to shared projects. Music, as a universal form of expression, helps create connections between students and encourages interaction during group activities. Musical robotics projects such as building robot bands or developing automated musical performances allow learners to engage in a variety of roles, from programming and assembling the device to designing sound sequences and finally focusing on experimenting with musical ideas. This multidisciplinary approach enriches the learning experience, making musical concepts more accessible, interactive, and engaging for students while strengthening the integration between music and technology (Hodges 2019).

2.2 Sheet Music, Musical Notes, and Accidentals

In terms of knowledge, a musical note is a graphical symbol that represents the pitch and duration of a sound in music. These notes constitute the fundamental elements of the musical language and are used to represent the various sounds that make up a musical piece. Each note has a specific pitch, indicating how high or low the sound is, and a duration, which determines how long the note should be played (COUTO 2019*b*).

There are seven basic musical notes, which are identified by letters of the alphabet as: A, B, C, D, E, F, and G. After the G note, the pattern repeats, one octave above, and so on, depending on the number of tones an instrument can play. For example, the official number of notes for a piano is 88. Among the 7 basic notes (A, ..., G), some of them can be altered by musical accidentals, such as sharps and flats, which means it is modified in their pitch, one tone above or below. The notes that do not have a natural sharp (without being enharmonic) are E and B. This occurs because between E and F, and between B and C, there is only a semitone distance, and there is no space for an intermediate note with a sharp. Thus, this gives in total 12 musical tones (excluding the 2 that do not have sharp), which forms an octave. The human voice can reach a wide range of musical pitches, typically ranging from 2 to 4 octaves, with some notable singers reaching up to 8 octaves. This vocal range can vary significantly between individuals and is influenced by factors such as sex, age, and vocal technique.

Each musical note corresponds to a specific frequency value, generally representing the most prominent or intense harmonic component of the corresponding sound (COUTO 2019*b*). Figure 2.1 presents the frequencies associated with each basic note. In the context of Arduino, one only needs to use the *tone()* function on a pin connected to the speaker or buzzer, employing the frequency in hertz (Hz) corresponding to the desired note, as indicated in the figure.

Music is applied in numerous situations in society, especially during moments of achievement, characterized as celebratory and joyful. Musical elements such as major tones, fast rhythms, ascending melodies, and consonant harmonies, along with positive lyrics about celebration and victory, help convey feelings of joy and festivity. However, music is also used during times of sadness and as warning signals (Cochrane et al. 2013).

It is common to find music in rescue situations, such as in ambulances, police vehicles,

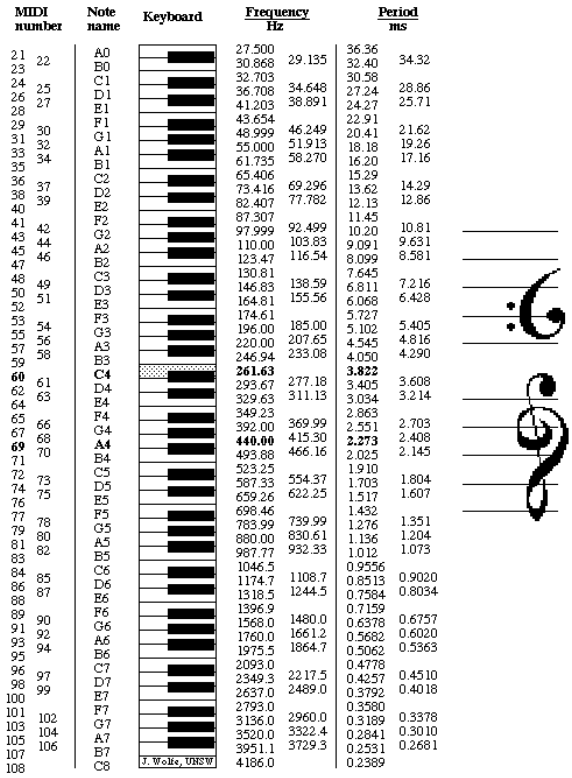

Figure 2.1: Musical notes and their frequencies

and fire trucks. In such cases, choosing appropriate music can be crucial to support both the rescue team and the victims. Energetic music helps to motivate and energize rescuers, while calming songs can soothe victims and reduce stress. Instrumental soundtracks are effective for maintaining focus and concentration, and rhythmic music helps synchronize the team's actions. After the rescue, cheerful music helps boost everyone's morale. The choice of music must be made carefully to avoid interfering with communication and safety during operations.

In a race, music can be used to signal the start and completion of a task, and in a rescue race, it can also signal that the target has been saved. Music that marks the beginning and end of courses is frequently used in various contexts such as ceremonies, sports events, movies, TV series, and even in everyday life to mark specific moments of transition or completion. There are well-known pieces of music that characterize these moments, such as start sounds that indicate a competition has begun and task completion sounds. An example of a start sound is from the game "Mario Kart," created by Kenta Nagata (MarioWiki 2024). An example of a task completion sound is the "treasure chest open" sound in "The Legend of Zelda" series, created by Koji Kondo (Zelda Wiki 2024).

2.3 Music and Microcontrollers

Music can be produced with microcontrollers through programming and the construction of simple electronic circuits. By using components such as piezo buzzers or speakers, it becomes possible to generate tones, melodies, and sound effects. The choice of components and the specific microcontroller depends on the desired complexity of the musical project, and a variety of libraries are available to simplify the integration between electronics and music.

The Arduino platform is one of the most commonly used tools for this purpose. It enables the generation of musical tones and even the playback of audio files, allowing the development of both simple melodies and more elaborate musical applications. Libraries such as *Mini Music* and *Playtune* expand these possibilities, while direct programming offers flexibility for the creation of customized musical sequences. Although sound quality varies depending on the hardware configuration, the combination of software and basic electronic components provides a rich environment for creative experimentation.

A fundamental aspect of music creation on Arduino is its monophonic nature when using native resources. The microcontroller can play only one note at a time, a limitation that aligns with the operating mode of the built-in `tone()` function, which generates square-wave signals corresponding to specific frequencies. This simplicity makes it suitable for educational contexts as it helps students understand the basic relationships between pitch, frequency, and timing. However, producing polyphonic music (multiple notes played simultaneously) requires additional libraries, specific strategies, or extra-hardware components to overcome the limitations of the standard approach (COUTO 2019*a*).

2.4 Resuming From Theory to Practice

The concepts discussed in this chapter establish a very basic theoretical foundation for understanding the educational proposal developed in this study. As the focus here is to experimentally verify the application of Robotics to Music, more advanced concepts in Music, Computing, and Robotics will not be necessary for the understanding of the whole picture.

As a practical result, we have built and will use in practice an artifact, which we called EcoMusic, that allows the application of Educational Robotics into Music, abstracting the complexity and making it simple for teachers and students. Hence, these basic principles guide the design decisions presented in subsequent Chapters, in which the proposed artifact is described and evaluated within a classroom context with Music learning as the focus.

Chapter 3

Related Works

This chapter aims to present existing work related to the theme of musicalization with educational robotics, addressing initiatives, projects, and research that explore the integration between educational technologies and music. We start by presenting these found texts and then we provide a comparison of our approach with them.

3.1 Articles, Ph. D. Thesis and Masters' Dissertations

From the works described next, there are some of them which are very related to ours, which will be discussed after this Section.

3.1.1 Open-Source Robotics as a Didactic Alternative for Music Learning

The dissertation entitled "Open-Source Robotics as a Didactic Alternative for Music Education", authored by Sabrina F. Antunes, Adriano C. Teixeira, and Mario Pireddu, published in the journal New Technologies in Education (in Portuguese), in December 2017, explores the use of open-source robotics as an innovative and accessible pedagogical strategy for teaching music. The study is grounded in the reality faced particularly by public schools, which even after the enactment of Brazilian Law No. 11.769/2008 — making music education mandatory in basic education — continue to struggle with a lack of musical instruments and qualified professionals (Antunes et al. 2017). The main goal of the research was to develop and implement an electronic device based on open-source robotic technology, aimed at supporting the musicalization process of children. The methodology adopted was qualitative and exploratory, based on the principles of the Orff approach, which emphasizes body movement, simple instruments, and creative expression as key elements of musical learning. The study is carried out through four experimental workshops with children aged 10 to 12. In these sessions, the device was integrated into hands-on activities that promoted sound experimentation, collaborative work, and the interplay of rhythm, body, and technology. Data were collected through participant observation and interviews, allowing an in-depth analysis of student interactions and learning experiences.

The findings showed that the use of open-source robotics significantly contributed to the development of the children's musical skills, leading to noticeable improvements in their understanding of sound elements, logical reasoning, and engagement with musical activities. The combination of technical aspects of robotics with creative musical practices proved to be an effective approach, especially in educational settings marked by structural and financial limitations.

Furthermore, the use of open hardware and low-cost electronic components reinforces the feasibility of the proposal, making it especially suitable for schools with limited resources. The dissertation highlights the transformative potential of interdisciplinary approaches that combine technology, art, and education. It represents a valuable contribution to both the fields of music education and educational robotics, by proposing a methodological alternative that aligns with contemporary demands for innovation, inclusion, and the holistic development of students.

3.1.2 Social robotics in music education: A systematic review

The article entitled "Social Robotics in Music Education: A Systematic Review" presents a detailed overview of how social robotics has been used in music education, based on a systematic review of the scientific literature. The main goal of the study is to examine how this technology has been applied in educational settings, considering its potential to enrich the learning experience through closer and more engaging social interactions (Martinez-Roig et al. 2023).

Social robotics, due to its multidisciplinary nature, involves the development of robots capable of interacting with humans in collaborative and expressive ways. In the context of music education, these robots have been used as support tools in the teaching process, particularly because of their ability to offer dynamic interactions that adapt to students' individual needs.

The study mapped and analyzed research that explores various applications of these robots in music education, using rigorous selection criteria. The reviewed works demonstrate a wide range of uses for social robotics — from teaching music theory and instrumental practice to activities focused on rhythm, melody, and musical creativity, such as composition.

Among the key findings is the ability of social robots to simulate aspects of human communication — such as providing immediate feedback and basic emotional expressions — which tends to enhance student engagement and make the learning process more appealing. The analyzed studies report benefits such as increased student participation, improved focus during activities, and the development of musical skills in a playful and innovative way.

On the other hand, the article also highlights some important challenges. These include the high cost of the robots, the technical complexity involved in operating them, the difficulty in adapting musical content to robotic interfaces, and limitations in recognizing and interpreting more subtle musical and emotional nuances. The study also points to a lack of long-term research on the effects of using social robotics in music education, as well as a shortage of studies with diverse samples and school settings.

Given this scenario, the article reinforces the need to expand research in this area, with a focus on gaining a deeper understanding of the actual impact of this technology on students' musical development. It also suggests that future studies should explore the development of robots with greater emotional and musical sensitivity, and seek to broaden their use across different age groups and educational levels — especially in under-resourced contexts where there is a shortage of specialized music teachers.

In conclusion, the article presents social robotics as a promising alternative for innovation in music education, contributing to a more accessible, inclusive, and contemporary approach to teaching and learning music.

3.1.3 Music-mathematics teaching-learning using educational robotics

The study entitled "Music-mathematics teaching-learning using educational robotics", investigates the interdisciplinary integration between the domains of music and mathematics through the application of educational robotics as a pedagogical tool. The central aim of the research is to analyze how robotics can be used to facilitate the simultaneous learning of musical and mathematical concepts, considering the intrinsic and structural relationship between these fields of knowledge (Ahijado 2019).

Starting from the premise that music and mathematics share structural foundations—such as rhythm, proportion, sequences, and patterns—the study explores the potential of educational robotics to enable a practical and playful approach to these concepts. The use of robotic kits and platforms allows students to build, program, and interact with robots capable of performing actions that reflect musical principles, such as rhythms and scales, while also applying mathematical notions including fractions, counting, and sequencing.

The research emphasizes that educational robotics promotes an interdisciplinary approach that brings greater meaning and motivation to the learning process. The hands-on manipulation of robots supports the development of mathematical skills while enabling an active musical experience, facilitating the understanding of abstract concepts through experimentation and practical engagement.

Moreover, the study highlights that using robotics in music-mathematics education contributes to the development of essential 21st-century skills such as logical thinking, problem-solving, creativity, and collaborative work. It also underscores the importance of active methodologies and student agency in knowledge construction—fundamental elements for the pedagogical success of this approach.

The results indicate a significant increase in student engagement, greater ease in assimilating complex mathematical concepts, and an enhanced perception of the interrelationship between music and mathematics. Thus, educational robotics is shown to function as an effective bridge for integrating traditionally separate content areas, promoting contextualized and interdisciplinary learning.

Finally, the study suggests the need for future research to deepen this interdisciplinary approach, expand the application of educational robotics across different educational levels, and diversify pedagogical strategies to address the heterogeneity of students and their diverse educational needs.

3.1.4 Toward Robotic Musicianship

The article entitled “Toward Robotic Musicianship” addresses the development of robots capable of acting as autonomous musicians, exploring the emerging concept of “robotic musicianship.” The research focuses on the integrated application of robotics and artificial intelligence to create systems that go beyond mere sound reproduction or instrumental execution, enabling interpretation, improvisation, and interactive musical collaboration with human musicians (Weinberg & Driscoll 2006).

The study thoroughly discusses the technical and artistic challenges associated with building robotic musicians, including refined musical perception, precise motor control, real-time processing, and musical expression encompassing rhythmic, dynamic, and emotional nuances. Furthermore, it highlights the importance of fluid and responsive interaction between robots and human musicians, which is essential for achieving natural, cohesive, and creative joint performances.

Throughout the study, various approaches and prototypes are presented, showcasing advanced capabilities such as automatic improvisation, temporal synchronization with other musicians, adaptation to diverse musical styles, and the generation of context-aware musical responses. The article also underscores the relevance of sophisticated machine learning algorithms and signal processing techniques to enable robotic systems to understand and respond effectively to the complexities of live music.

As a key contribution, the article proposes an integrative conceptual model to guide future research, addressing the technical, musical, and social aspects essential to the advancement of musical robotics. It also emphasizes the potential of these systems to expand the boundaries of musical creation, offering new forms of interaction and artistic expression.

In summary, the study represents a significant step forward in the development of robotic musicians capable of surpassing simple mechanical execution and approaching authentic musicality. This progress opens up new perspectives for innovative performances, enriched music education, and deeper interdisciplinary research.

sectionUbiquitous Computing for Music Education with Makey Makey

The article entitled “Ubiquitous Computing for Music Education with Makey Makey” investigates the use of ubiquitous computing to enhance music education in primary school settings. The study explores how interactive environments can transform classrooms into “musical laboratories,” where simple body interactions, such as clapping or stepping, are converted into musical sounds using the Makey Makey device (Santos et al. 2015).

The research emphasizes the integration of educational theories, including socioconstructivism, musical discourse, and embodied learning, to support collaborative and active learning experiences. The study highlights how the Makey Makey facilitates the reduction of technical barriers, enabling students to experiment with sound and rhythm without prior musical training.

Methodologically, the study adopts a Design Science Research (DSR) approach, focusing on the development and evaluation of the "Intelligent Musical Mat," which translates physical interactions into digital sound responses. Field experiments were conducted in public schools with 7th-grade students, demonstrating that the system fosters engagement, collaboration, and creativity.

The results indicate that students and teachers responded positively to the artifact, confirming its potential to enhance musical understanding and expression. Additionally, the study identifies necessary conditions for successful implementation, such as adequate school infrastructure and support for exploratory learning activities.

In summary, the article presents a practical and pedagogically grounded application of ubiquitous computing in music education. It shows how low-cost, interactive technologies like the Makey Makey can create inclusive, collaborative, and engaging musical experiences that bridge technology and creative learning.

3.1.5 Music-Therapy Robotic Platform for Children with Autism

The article entitled "A Music-Therapy Robotic Platform for Children with Autism: A Pilot Study" presents an innovative robotic platform designed to improve social and behavioral responses in children with Autism Spectrum Disorder (ASD) through music-based interactions (Feng et al. 2022).

The study describes a system composed of three main modules: sound detection, intelligent scoring with real-time feedback, and emotion classification using machine learning. The platform converts musical interactions, such as playing a xylophone, into adaptive auditory and visual responses, while monitoring physiological signals like electrodermal activity (EDA) to classify emotional states.

During the pilot study, nine children with ASD and seven typically developing children participated in 50 interactive sessions. The results demonstrated that most participants completed motor control tasks with approximately 70% accuracy. Six of the nine children with ASD exhibited stable turn-taking behaviors when playing music, and automated emotion classification effectively detected emotional arousal in the ASD group using EDA signals.

The study highlights the potential of robot-assisted music therapy to enhance fine motor skills, social turn-taking, and emotion recognition in children with ASD. By integrating machine learning and human-robot interaction, the platform offers personalized and adaptive therapeutic interventions, providing promising directions for future educational and therapeutic applications.

3.1.6 'How Would you Score Yourself?': The Effect of Self-assessment Strategy Through Robots on Children's Motivation and Performance in Piano Practice

The study entitled *"How Would You Score Yourself?": The Effect of Self-assessment Strategy Through Robots on Children's Motivation and Performance in Piano Practice* investigates how interaction with social robots influences children's motivation and performance during piano practice. The research explores the use of robots that initiate self-assessment prompts and provide feedback to foster self-regulated learning in musical practice (Song et al. 2024).

The study was conducted in a music school with 50 children, who practiced piano under two experimental conditions: one involving a robot that actively initiated self-assessment, and another involving a robot that did not provide evaluative feedback. The results indicate that children who interacted with the self-assessment-initiating robot demonstrated higher levels of motivation and improved musical performance compared to those in the non-evaluative condition.

Furthermore, interaction effects were identified between the robot condition, learning stage, and gender, influencing both motivational outcomes and rhythmic performance (Song et al. 2024). These findings highlight the importance of designing personalized child–robot interactions that take into account individual and developmental characteristics.

Overall, this study contributes to the understanding of how educational robotics can support musical learning by enhancing motivation, self-regulation, and performance in children's instrumental practice.

3.2 Strict Related Works and Comparative Synthesis

The work of Antunes et al. (2017) focuses on the use of open source robotics for music learning, while Martinez-Roig et al. (2023) presents a systematic review on the subject, seeking to investigate the application of social robotics in the context of music education. Ahijado (2019), in turn, investigates the interdisciplinary integration between the domains of music and mathematics through the application of educational robotics as a pedagogical tool. Finaly, yet very related, Weinberg & Driscoll (2006) discusses the development of robots capable of acting as autonomous musicians.

For a broader comparison, we include other works, and the main particular characteristics of them are enumerated, such as:

- Antunes et al. (2017) highlights the use of open-source robotics as a tool for music education;
- Martinez-Roig et al. (2023) provides a systematic review of social robotics applications in music education;

- Ahijado (2019) explores interdisciplinary connections between music and mathematics through educational robotics;
- Weinberg & Driscoll (2006) concentrates on the development of autonomous robotic musicians;
- Santos et al. (2015) investigates ubiquitous and body-based musical interactions using Makey Makey to reduce technical barriers in classrooms;
- Feng et al. (2022) presents a robot-assisted music therapy platform aimed at supporting children with autism;
- Song et al. (2024) examines the motivational role of social robots in piano practice through self-assessment mechanisms;

The present work advances the state-of-the-art beyond predominantly theoretical, technical, or exploratory studies by presenting a practical and empirical investigation conducted in an authentic school environment, with direct observation of its effects on students engagement, learning processes, and interactions. Rather than focusing solely on technological development or conceptual discussions, this research emphasizes educational impact and pedagogical intentionality. The present study distinguishes itself by focusing on the intentional integration of educational robotics into musicalization as a pedagogical strategy, which is systematically analyzed within a real classroom context. The emphasis is not only on the technological artifact, but also on how its use mediates learning, collaboration, creativity, and student engagement.

Beyond its alignment with the Brazilian National Common Core Curricular Basis (BNCC), this research contributes to the understanding of how interdisciplinary, hands-on, and student-centered approaches can foster meaningful learning experiences, bridging musical, electronic, and computational concepts in basic education.

3.3 Comparative Overview of Robotics Kits

Table 3.1 depicts the main educational robotics kits that integrate sound and/or music, such as *Makey Makey*, *LEGO SPIKE Prime*, *LittleBits Synth Kit*, and *Arduino*-based musical projects. These kits present different levels of potential for educational purposes, however, they share structural limitations when compared to *EcoMusic*. It is important to note that these kits were not originally designed specifically for music education; however, they allow musical elements to be incorporated as complementary resources within broader technological and interdisciplinary learning activities.

The *Makey Makey*, created by Jay Silver and Eric Rosenbaum (Santos et al. 2015), became popular for its simplicity and playfulness, enabling the transformation of conductive objects into musical interfaces. Although not conceived as a music education tool, it allows students to explore sound production and interaction in an intuitive manner. However, its emphasis on immediate experimentation limits deeper engagement with electronic or programming principles.

The *LEGO SPIKE Prime* (LEGO Education 2020) combines modular robotics, sensors, and block-based programming and is widely adopted in formal education. While the kit was not developed with a specific focus on musical learning, it supports activities involving sound and rhythm through programmable motors and sensors. Despite its strong potential in logic and engineering education (Petrovič & Agarshev 2024), its high cost and reliance on proprietary industrial components restrict accessibility for many schools.

Similarly, the *LittleBits Synth Kit*, designed by Ayah Bdeir (Bdeir 2014), introduces students to sound design and electronic synthesis. Although it enables musical experimentation, its primary goal is not formal music education. Its pre-assembled modular architecture often places learners in the role of assemblers, reducing opportunities for deeper creative or technical exploration (Blikstein 2018).

The Arduino platform, documented by Banzi and Shiloh (Banzi & Shiloh 2022),

Table 3.1: Comparison between educational robotics kits and EcoMusic

Kit	**Technological Focus**	**Sound Resources**	**Materials**	**Cost / Access**	**Sustainability**	**Difference Compared to EcoMusic**
Makey Makey	Conductive USB interface	Sound via software (Scratch, SoundPlant)	Conductive objects	Medium (imported)	Low	EcoMusic includes programming, electronics, and recycled materials.
LEGO SPIKE Prime	Modular robotics with sensors	Limited built-in sounds	Plastic blocks	High	None	EcoMusic is accessible, ecological, and musically expressive.
LittleBits Synth Kit	Electronic sound modules	Analog/digital synthesis	New components	High	Low	EcoMusic fosters hands-on building and collaborative sustainability.
Arduino musical projects	Microcontrollers and sensors	Sound via buzzer or speaker	Mixed components	Variable	Medium	EcoMusic offers structured, interdisciplinary pedagogy.
EcoMusic	Microcontroller and custom sound shield	Programmable melodies	Recycled materials	Low	High	Integrates robotics, music, and ecology into an inclusive learning model.

Prepared by the author (2025), based on Resnick et al. (Resnick et al. 2017), Santos (Santos et al. 2015), LEGO (LEGO Education 2020), Petrovic et al. (Petrovič & Agarshev 2024), Bdeir (Bdeir 2014), Blikstein (Blikstein 2018), Banzi and Shiloh (Banzi & Shiloh 2022), Garcia et al. (García-Tudela & Marín-Marín 2023), and Andrade (Andrade et al. 2024).

supports open prototyping and physical computing, making it suitable for a wide range of educational applications. Among these, some studies have explored the use of Arduino in musical activities, allowing students to work with sound-related concepts such as rhythm and pitch (García-Tudela & Marín-Marín 2023). Nevertheless, such initiatives often lack structured pedagogical guidance or explicit alignment with national curricular frameworks, including Brazil's BNCC.

In this scenario, *EcoMusic*, developed by Andrade (Andrade et al. 2024), emerges as an interdisciplinary alternative that integrates music, robotics, and environmental awareness from its conceptual foundation. Built with recycled materials and low-cost microcontrollers, the kit promotes active and collaborative learning while encouraging reflection on sustainability. Additionally, it aligns with BNCC general competencies, fostering not only cognitive and technological skills but also socio-emotional dimensions such as cooperation, empathy, listening, and shared responsibility.

By articulating affordability, ecological awareness, and pedagogical intentionality, *EcoMusic* offers a humanized model of educational robotics that supports students' comprehensive development and broadens access to meaningful technological learning experiences.

The comparison reveals that EcoMusic advances in three key dimensions: (1) sustainability through the reuse of electronic waste; (2) full integration of art, technology, and curriculum; and (3) purposeful incorporation of musical elements to make learning more engaging, creative, and meaningful. These characteristics position it as an educational robotics tool aligned with contemporary educational innovation and the interdisciplinary demands of 21st-century teaching.

Chapter 4

Problem and Proposed Solution

Although musicalization is widely recognized as a resource capable of stimulating multiple dimensions of human development—cognitive, emotional, and social—its teaching through educational robotics as a pedagogical mediator, particularly in alignment with the guidelines of the Brazilian National Common Curriculum Base (BNCC), remains underexplored and insufficiently understood in formal educational contexts.

In this sense, the following research question arises: How can the incorporation of educational robotics into musicalization foster greater engagement, motivation, and meaningful learning in music education?

Investigating this question is essential to understand whether musicalization, when mediated by educational robotics, can enhance student engagement and learning while fostering essential 21st-century competencies, such as creativity, collaboration, emotional self-regulation, and logical reasoning. This investigation also provides a foundation for innovative pedagogical practices aligned with contemporary educational demands. In order to help answer this question, we propose EcoMusic, a system designed to support the teaching of musicalization through educational robotics.

EcoMusic is designed to enable students to create and explore music they enjoy through an educational robotics project. It functions as an interactive musical speaker box, allowing students to create and play their own music by pressing buttons. Through programming, the system can play two different melodies, with each button triggering a distinct song. The buttons may also be assigned additional functions, such as starting or stopping a song, depending on the programmed logic. User interaction with EcoMusic is defined by the programming and the electronic connections established, following the functional specifications of the shield and the external PCB (Andrade et al. 2024).

The project is intended for classroom use with students across the educational levels covered by the BNCC. To engage with EcoMusic, students require basic prior knowledge of programming, as well as an introductory understanding of musical melodies and the operation of the Arduino microcontroller.

4.1 BNCC Skills for Music Education

To start building the project, we examined the BNCC skills to identify which subjects covered the necessary means and materials, ensuring that the project met the needs of students at the early childhood, elementary, and high school levels, as depicted next. The skills presented here are related to the motivation for the construction and the intended future use of EcoMusic in the classroom.

4.1.1 Early Childhood Education

- (EI01TS01) Explore sounds produced with their own body and with objects from the environment;
- (EI02TS01) Create sounds using materials, objects, and musical instruments to accompany various music rhythms;
- (EI03TS01) Use sounds produced by materials, objects, and musical instruments during pretend play, enactments, musical creations and parties;
- (EI03TS02) Express themselves freely through drawing, painting, collage, folding, and sculpture, creating two-dimensional and three-dimensional productions;
- (EI01TS03) Explore different sound sources and materials to accompany singing

games, songs, music, and melodies;

- (EI02TS03) Use different sound sources available in the environment in singing games, songs, music, and melodies;
- (EI03TS03) Recognize the qualities of sound (intensity, duration, pitch, and timbre), using them in their sound productions and when listening to music and sounds;
- (EI01EF02) Demonstrate interest in listening to the reading of poems and the presentation of music;
- (EI02EF02) Identify and create different sounds and recognize rhymes and alliterations in nursery rhymes and poetic texts;
- (EI03EF02) Invent singing games, poems, and songs, creating rhymes, alliterations, and rhythms;
- (EI02ET01) Explore and describe similarities and differences between the characteristics and properties of objects (texture, mass, size);
- (EI03ET01) Establish comparison relationships between objects, observing their properties;
- (EI01ET05) Manipulate various materials to compare their differences and similarities;
- (EI02ET05) Classify objects considering specific attributes (size, weight, color, shape, etc.);
- (EI03ET05) Classify objects and figures according to their similarities and differences.

4.1.2 Elementary School - 1st Grade

- SCIENCE (EF01CI01) Compare characteristics of different materials found in everyday use objects, discussing their origin, how they are disposed of, and how they can be used more consciously;
- MATHEMATICS (EF01MA14) Identify and name plane figures (circle, square,

rectangle, and triangle) in drawings presented in different arrangements or as contours of faces of geometric solids;

- ARTS (1st to 5th year of Elementary School) (EF15AR26) Explore different technologies and digital resources (multimedia, animations, electronic games, audio and video recordings, photography, software, etc.) in artistic creation processes.

4.1.3 Elementary School - 2nd Grade

- SCIENCE (EF02CI01) Identify what materials (metals, wood, glass, etc.) everyday objects are made of, how these objects are used, and with which materials they were produced in the past;
- SCIENCE (EF02CI02) Propose the use of different materials for the construction of everyday objects, considering some properties of these materials (flexibility, hardness, transparency, etc.);
- GEOGRAPHY (EF02GE10) Apply principles of location and position of objects (spatial references such as front and back, left and right, up and down, inside and outside) through spatial representations of the classroom and school;
- MATHEMATICS (EF02MA14) Recognize, name, and compare spatial geometric figures (cube, rectangular block, pyramid, cone, cylinder, and sphere), relating them to objects in the physical world;
- MATHEMATICS (EF02MA15) Recognize, compare, and name plane figures (circle, square, rectangle, and triangle) based on common characteristics, in drawings presented in different arrangements or in geometric solids.

4.1.4 Elementary School - 3rd Grade

- SCIENCE (EF03CI01) Produce different sounds from the vibration of various objects and identify variables that influence this phenomenon;

- SCIENCE (EF03CI03) Discuss habits necessary for maintaining auditory and visual health considering environmental conditions in terms of sound and light;
- GEOGRAPHY (EF03GE08) Relate the production of household or school waste to problems caused by excessive consumption and develop proposals for conscientious consumption, considering the expansion of habits of reduction, reuse, and recycling/disposal of materials consumed at home, school, and/or in the surroundings;
- MATHEMATICS (EF03MA13) Associate spatial geometric figures (cube, rectangular block, pyramid, cone, cylinder, and sphere) with objects from the physical world and name these figures;
- MATHEMATICS (EF03MA19) Estimate, measure, and compare lengths using common non-standard and standard units of measurement (meter, centimeter, and millimeter) and various measuring instruments.

4.1.5 Elementary School - 4th Grade

- MATHEMATICS (EF03MA13) Associate spatial geometric figures (cube, rectangular block, pyramid, cone, cylinder, and sphere) with objects from the physical world and name these figures.

4.1.6 Elementary School - 5th Grade

- SCIENCE (EF05CI05) Develop collective proposals for more conscious consumption and create technological solutions for proper disposal and reuse or recycling of materials consumed at school and/or in daily life;
- HISTORY (EF05HI06) Compare the use of different languages and technologies in the communication process and evaluate the social, political, and cultural meanings attributed to them.

4.1.7 Elementary School - 8th Grade

- SCIENCE (EF08CI02) Build electrical circuits using battery, wires, and bulbs or other devices, and compare them to residential electrical circuits;
- SCIENCE (EF08CI03) Classify residential electrical appliances (such as shower, iron, lamps, TV, radio, refrigerator, etc.) according to the type of energy transformation (from electrical energy to thermal, light, sound, and mechanical energy, for example).

4.1.8 High School - Languages and their technologies

- (EM13LGG603) Express oneself and engage in individual and collective authorial creation processes in different artistic languages (visual arts, audiovisual, dance, music, and theater) and their intersections, drawing on aesthetic and cultural references, diverse knowledge (artistic, historical, social, and political), and individual and collective experiences;
- (EM13LGG701) Explore digital information and communication technologies (ICTs), understanding their principles and functionalities, and use them ethically, creatively, responsibly, and appropriately in language practices in different contexts;
- (EM13LGG702) Evaluate the impact of digital information and communication technologies (ICTs) on the formation of individuals and their social practices, to critically use this media in practices of selection, understanding, and production of discourses in digital environments;
- (EM13LGG703) Use different languages, media, and digital tools in processes of collective production, collaboration, and authorial projects in digital environments;
- (EM13LGG704) Critically appropriate research processes and information search through tools and new formats of knowledge production and distribution in networked culture.

4.1.9 High School - Portuguese Language

- (EM13LP20) Share preferences, interests, cultural practices, themes/problems/questions that arouse greater interest or concern, respecting and valuing differences, as a way to identify common affinities and interests, as well as to organize and/or participate in groups, clubs, workshops, and similar activities;
- (EM13LP21) Collaboratively produce and share annotated playlists of cultural and entertainment preferences, cultural magazines, fanzines, e-zines, or similar publications that promote, comment on, and evaluate music, games, series, movies, comics, books, plays, exhibitions, dance performances, etc., in order to share tastes, identify affinities, and foster communities;
- (EM13LP22) Collaboratively build and/or update dynamic records (maps, wikis, etc.) of professions and occupations of interest (areas of expertise, information on training, activities, productions, professional testimonials, etc.) that allow envisioning personal and professional trajectories.

4.1.10 High School - Natural sciences and technologies

- (EM13CNT308) Investigate and analyze the operation of electrical and/or electronic equipment and automation systems to understand contemporary technologies and assess their social, cultural, and environmental impacts;
- (EM13CNT309) Analyze socio-environmental, political, and economic issues related to the current world's dependence on non-renewable resources and discuss the need for introducing alternatives and new energy and material technologies, comparing different types of engines and processes for producing new materials.

4.2 Circuit Assembly

EcoMusic was designed as an educational robotic artifact and maker-oriented device capable of producing musical sounds using recycled materials and electronic components. Although it does not perform autonomous decision-making or environmental sensing, it is situated within the context of educational robotics because it integrates electronics, programming, and physical construction to enable interactive sound production.

The device was developed to support the learning of musical, programming, and basic electronics concepts in a practical and engaging way, fostering creativity, logical reasoning, and hands-on experimentation.

To accomplish this project, the following materials were required:

- Recycled cardboard box
- Conductive wires
- Speaker or buzzer
- Arduino UNO R3
- 2 Push Buttons
- 2 10 KΩ Resistors
- Glue, tape, scissors, and utility knife
- Cutting and drilling tools

The electronic circuit is shown in Fig.4.1. It has two push buttons intended to play a melody when pressed, which is output through the recycled electronic waste speaker. In addition, two 10 kΩ pull-down resistors (resistors connected to GND) are used. The buttons are connected to digital pins 2 and 3, and the speaker is connected to pin 4.

Based on this electronic circuit, it was possible to program the microcontroller as shown in Fig. 4.2, where it can be noted that two random frequencies were used in the melodies.

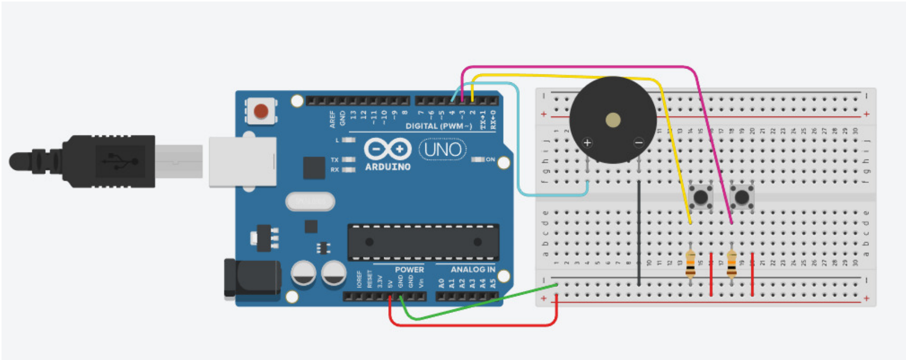

Figure 4.1: Circuit of EcoMusic.

```
const int Button1 = 2; // Pino do primeiro Botão
const int Button2 = 3; // Pino do segundo Botão
const int Buzzer = 4; // Pino do buzzer
int song1[] = {262, 294, 330, 349, 392, 440, 494, 523};
int song2[] = {392, 440, 494, 523, 587, 659, 698, 784};

void setup() {
  pinMode(Button1, INPUT);
  pinMode(Button2, INPUT);
  pinMode(Buzzer, OUTPUT);
}

void loop() {
  int touchValue1 = digitalRead(Button1);
  int touchValue2 = digitalRead(Button2);

  if (touchValue1 == HIGH) {
    playSong(song1);
    delay(100);
  }

  if (touchValue2 == HIGH) {
    playSong(song2);
    delay(100);
  }
}

void playSong(int song[]) {
  int songLength = 8;
  for (int i = 0; i < songLength; i++) {
    int noteDuration = 500;
    tone(Buzzer, song[i], noteDuration);
    delay(noteDuration);
    noTone(Buzzer);
  }
}
```

Figure 4.2: Arduino code for EcoMusic.

4.2.1 Assembly of the EcoMusic Structure

EcoMusic has also been designed as a speaker box. In its construction, recyclable materials were used to assemble its structure. Its dimensions were adjusted to fit the size of the speaker, using cardboard to build the structure based on the speaker's dimensions. Fig. 4.3 shows the step-by-step process of this construction, which includes: a) the speaker from electronic waste; b) the recycled cardboard box; c) the face of the EcoMusic Robot printed on adhesive paper; d) the rear of the structure that holds the speaker; e) the front of the robot; and f) the painted black cardboard box, finished with the inclusion of the speaker structure.

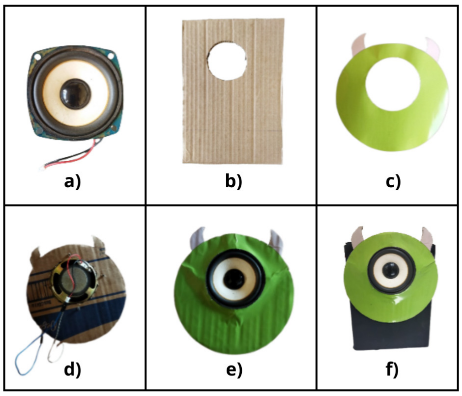

Figure 4.3: Manufacturing process of the EcoMusic structure with speaker.

4.2.2 Creation Process of the Shield and External PCB

Considering the previous steps, two electronic schematics were created: one in the form of an Arduino shield and another as a simple PCB, which includes the buttons and resistors. The shield was designed to be attached to the Arduino UNO R3 microcontroller, while the simple PCB will be installed on the front of the EcoMusic.

The electronic schematic shown in Fig. 4.4a is for the shield, which has two components with three male pins (P2 and P3) and one component with two male pins (P1). P2 and P3 receive data from the simple PCB circuit, while P1 receives data from the speaker, all through connections with jumpers. Fig. 4.4b shows the shield for this circuit.

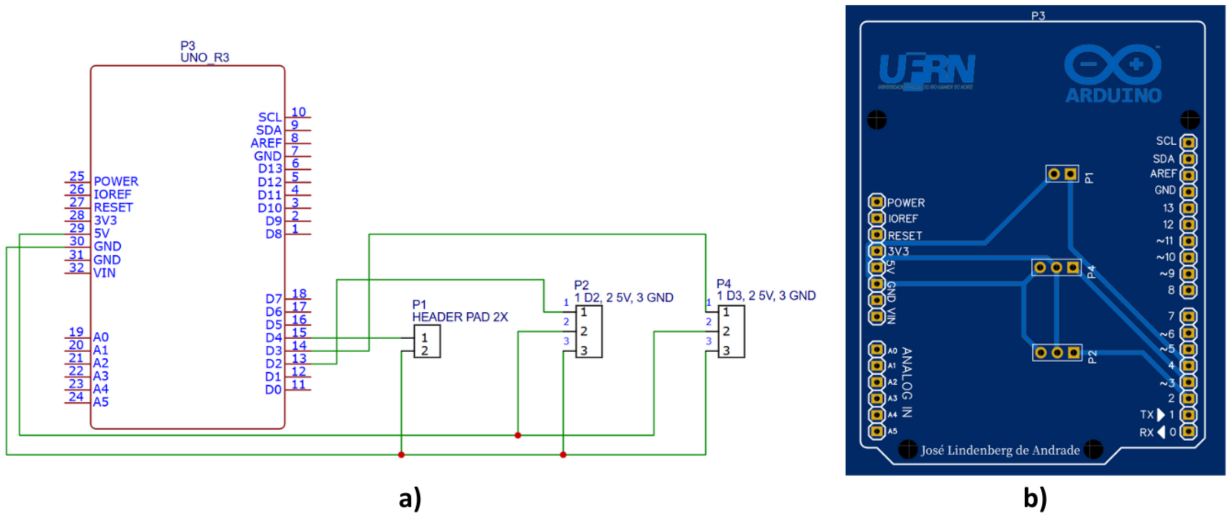

Figure 4.4: a) Schematic and b) Shield of the EcoMusic.

The electronic schematic of the simple PCB circuit is shown in Fig. 4.5a. It has two components with three male pins each (P2 and P3), which connect to the P1 and P2 pins of the shield using female jumpers. It also includes two push buttons and two 10 KΩ resistors. Figure 4.5b shows the PCB for this circuit.

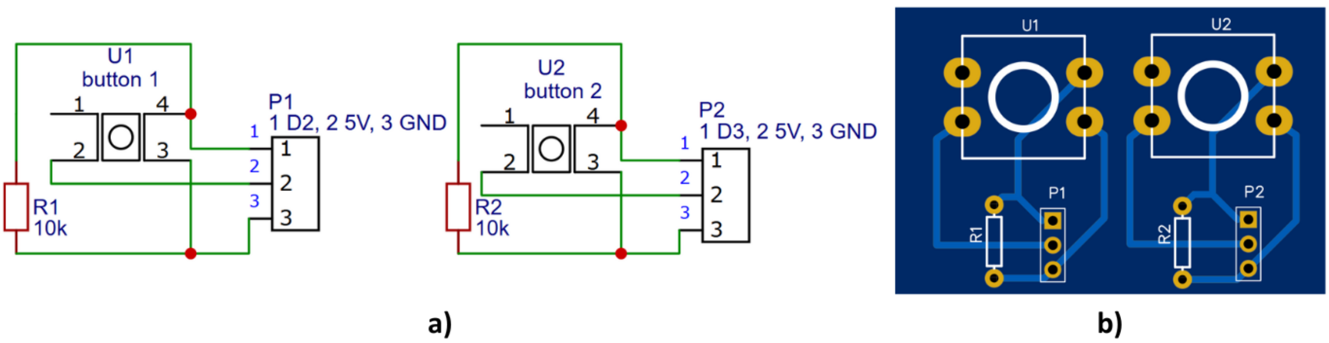

Figure 4.5: a) Schematic and b) External PCB of EcoMusic.

4.2.3 Manufacturing process of the Shield and the PCB of EcoMusic

The external PCB was produced manually. First, the PCB design was printed on photographic paper. Next, the print was transferred to a phenolic board using an iron, heating for about three minutes. Once the print adhered to the copper surface of the phenolic board, it was immersed in ferric chloride for approximately thirty minutes to remove the unnecessary copper. Afterward, the board was cleaned, revealing the necessary copper traces. With the board ready, the electronic components were soldered, as illustrated in Fig. 4.6a. Finally, the PCB was attached to the EcoMusic structure, as shown in Fig. 4.6b.

For the production of the EcoMusic shield, the PCB circuit had to be organized, mirrored, and exported in DXF format for the CNC mill used. With the copper paths of the EcoMusic shield defined, it was possible to solder the necessary components, as illustrated in Fig. 4.6c. Subsequently, fitting tests were conducted on the Arduino UNO R3 to verify that the shield was manufactured to the correct size.

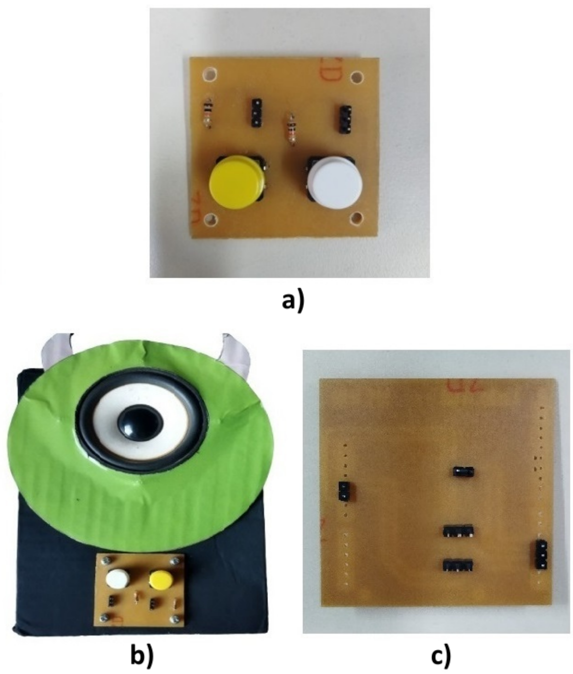

Figure 4.6: a) Components soldered on the PCB, b) PCB in the speaker enclosure, and c) EcoMusic Shield.

4.3 Research Implementation Schedule

The Table 4.1 presents the overall research schedule, summarizing how the different stages of the study were planned and effectively carried out. It illustrates the chronological development of the project—from ethical approval procedures to data collection, analysis, and dissertation preparation—providing a clear overview of the workflow implemented between April 2025 and December 2025.

The research began with the submission of the project to the Research Ethics Committee (CEP) in April 2025, in accordance with the ethical guidelines for studies involving human participants. After an initial review, minor adjustments were requested and incorporated, leading to a resubmission at the end of May. Final approval was granted later in the year, authorizing the start of the data collection process and classroom implementation.

Once ethical approval was secured, the preparation of research materials was completed, including the Free and Informed Assent Form (TALE), the Free and Informed Consent Form (TCLE), and student questionnaires. With all instruments ready, the study was implemented at Escola Municipal Josefa Botelho.

The classroom activities and application of questionnaires occurred in November 2025, involving 25 elementary school students from three robotics classes. During this phase, students participated in two instructional sessions of approximately two hours each, in which the EcoMusic project was introduced, explored, and evaluated. At the end of the activities, questionnaires were administered to collect data regarding student engagement, learning, and perceptions of the integration between music and educational robotics.

Following data collection, the stages of tabulation and analysis were conducted throughout November and early December. These findings supported the final writing, organization, and refinement of the dissertation. The defense of the study is scheduled for

Table 4.1: Schedule of activities performed

Execution steps	**Ap**	**My**	**Ju**	**Jl**	**Au**	**Se**	**Oc**	**No**	**De**
Submission of the research project to the Research Ethics Committee - CEP.	X	X	X						
Preparation of instruments for data collection – semi-structured interview script.				X					
Recruitment, application of the TCLE to parents/guardians, and the TALE to students; application of the questionnaire/semi-structured interview.					X	X			
Document analysis and writing of the Dissertation.					X	X	X	X	
Presentation to participants (objectives, methodology, risks and benefits) and authorizations (terms, voice-image).				X	X				
Application of the questionnaire to the research subjects.					X	X			
Conducting a semi-structured interview.					X	X			
Transcript of interviews.					X	X	X		
Tabulation of collected data.						X	X	X	
Analysis of collected data.							X	X	
Writing and final review of the Dissertation.								X	X
Dissertation Presentation.									X

December, marking the conclusion of the research cycle as outlined in the timeline.

4.4 Implementation in Classroom

This research was conducted with 25 elementary school students from Escola Municipal Professora Josefa Botelho. The implementation took place across three different classes, each participating in two sessions lasting approximately two hours, totaling four hours of activities per group. The sessions were integrated into the school's robotics curriculum, enabling students to explore the EcoMusic device and engage in musicalization activities within their regular learning environment.

The instructional activities were planned and designed by the researcher of the present study, with the support of the school's music teacher, a specialist in music education. This collaboration ensured pedagogical coherence between the proposed musicalization activities and the students' prior musical experiences, as well as alignment with the school curriculum and the guidelines of the Brazilian National Common Curriculum Base (BNCC).

Data collection occurred both during and immediately after the activities, using printed and digital questionnaires administered to the participating students. Additional feedback from teachers and interns involved in the robotics classes was also collected to enrich the analysis. When conducted, interviews lasted between 5 and 15 minutes and were carried out during short intervals between classroom activities.

The students had repeated contact with the EcoMusic device across two instructional sessions, allowing them to progressively build understanding through both conceptual introduction and hands-on application. The implementation was structured over two instructional days:

- **Day 1 – Introduction to Music and Frequency Concepts:** Students were introduced to fundamental musical concepts such as pitch, rhythm, and timbre. They also learned how musical notes can be converted into frequencies using standard reference tables. Although the focus of this session was conceptual, the EcoMusic device was already present in the classroom as a reference, helping students contextualize how these concepts would later be applied in practice.

- **Day 2 – Presentation of EcoMusic and Application of Frequency Conversion:** In the second session, students engaged directly and extensively with the EcoMusic device. The project was presented in detail, including its components, features, and sound-generation mechanisms. Students applied the frequency conversion concepts introduced on Day 1 to program melodies into EcoMusic. They practiced converting musical notes into numerical values and integrating them into programmed sequences, enabling the device to reproduce their musical creations.

After this introductory phase, the implementation followed the structure outlined below:

4.4.1 Lesson 1

Description of Lesson 1

Lesson 1 introduced students to the fundamental concepts of music and connected these concepts to the use of *EcoMusic*. The session was conducted in a practical and interactive format, enabling students to understand how sound, vibration, and frequency contribute to the formation of musical phenomena.

Introduction to the Concept of Music

The lesson began with a discussion defining music as the art of organizing sounds and silences to express emotions and ideas. Students were encouraged to share examples of music they enjoy, fostering a participatory and engaging learning environment.

Fundamental Elements of Music

The main musical elements were presented:

- **Rhythm**: the temporal organization of music.
- **Melody**: the principal component or the part that is sung.
- **Harmony**: sounds accompanying the melody.
- **Timbre**: the characteristic that differentiates instruments.
- **Silence**: pauses essential for musical structure.

These elements were explored through simple examples, helping students identify how they appear in familiar songs.

Sound and Vibration

Students explored the physical basis of sound, understanding it as the result of vibrations propagating through the air. A practical activity was conducted in which students touched their throats while producing low and high sounds, noticing the variation between slower and faster vibrations.

Musical Notes and Scale

The seven musical notes (*C, D, E, F, G, A, B*) were presented as the "steps" of a musical ladder. Through a brief physical exercise, students symbolically climbed and descended this ladder while adjusting their vocal pitch to represent higher (acute) and lower (grave) sounds.

Notes and Frequencies

Students learned the correspondence between musical notes and their frequencies, such as middle C at approximately 262 Hz. This content served as the mathematical basis for understanding how *EcoMusic* interprets and reproduces sound.

Converting Melodies into Frequencies

Students practiced converting a simple melody into a sequence of frequencies. The procedure included:

1. Selecting a short song, such as “Happy Birthday”.
2. Identifying its main notes.
3. Replacing each note with the corresponding frequency.
4. Preparing the list for programming into *EcoMusic*.

Monophonic Music

The concept of monophonic music—characterized by a single melody without harmonic accompaniment—was explained and illustrated using “Happy Birthday” sung in unison.

Conclusion

Lesson 1 concluded with a visualization in which students were shown the frequency corresponding to each musical note in “Happy Birthday,” establishing a foundation for future activities in which they would create their own melodies using *EcoMusic*.

4.4.2 Lesson 2

Description of Lesson 2

Lesson 2 expanded upon the concepts introduced in Lesson 1 by presenting the *EcoMusic* system—its purpose, construction, programming, and practical use in converting musical notes into frequencies. The session emphasized demonstration and hands-on exploration, reinforcing the idea of music as a technological, mathematical, and ecological phenomenon.

What is EcoMusic?

The lesson began with a formal introduction to *EcoMusic*, described as an Ecological Musical System. Students learned that EcoMusic integrates music, technology, and ecological concepts, enabling melodies to be played through frequency-based digital signals.

How EcoMusic Was Built

Students were shown how the EcoMusic device was constructed, observing:

- the electronic components used,
- the assembly of these components,
- and the role of each element in sound generation.

This helped students understand the device as a functional technological system built from sensors, actuators, and a microcontroller.

EcoMusic Programming

The programming of EcoMusic was demonstrated, highlighting the code responsible for converting notes into frequencies, controlling the buzzer, and sequencing the melody.

Although students did not write code during the session, the demonstration allowed them to observe:

- how the Arduino processes numerical values,
- how digital frequencies are generated,
- and how the code organizes the musical structure.

Musical Notes and Frequencies

Musical notes were revisited from a more technical perspective. Students were introduced to:

- MIDI numbering,
- international note naming (C, D, E, F, G, A, B),
- frequency values (Hz),
- and sound wave periods.

The concept of *octaves* was also introduced, demonstrating how the same note can appear at different pitch levels (e.g., C4, C5).

Analysis of "Happy Birthday"

Students applied the concepts learned by examining the melody of "Happy Birthday." During the activity, they analyzed:

- the segmentation of the song,
- the international note names,
- the corresponding frequencies,
- and how these values are implemented in *EcoMusic*.

Using the musical score and the frequency reference shown in Fig. 2.1, the students translated the melody into numerical values by converting each note into its frequency. For the Brazilian version of the song (CLAVEDEC 2023), this process was carried out in two distinct segments to support comprehension.

Part I: Happy birthday to you...

In the first segment, students identified the notes of the opening phrase and converted each pitch into its respective frequency. This activity helped them understand how symbolic musical notation can be represented numerically and later programmed into the EcoMusic device. Based on the score, they completed a table following the model below.

International Note	Note (Brazil)	Frequency (Hz)	Integer Value
G4	Sol	392.00 Hz	392
G4	Sol	392.00 Hz	392
A4	Lá	440.00 Hz	440
G4	Sol	392.00 Hz	392
C5	Dó	523.25 Hz	523
B4	Si	493.88 Hz	494

Table 4.2: Musical Notes and Their Frequencies (Part I)

Part II: On this special day...

For the continuation of the melody, students repeated the procedure, reinforcing the relationship between musical theory, computational representation, and its implementation in the robotic system. The converted values for this segment are shown below.

International Note	Note (Brazil)	Frequency (Hz)	Integer Value
G4	Sol	392.00 Hz	392
G4	Sol	392.00 Hz	392
A4	Lá	440.00 Hz	440
G4	Sol	392.00 Hz	392
D5	Ré	587.33 Hz	587
C5	Dó	523.25 Hz	523
C5	Dó	523.25 Hz	523

Table 4.3: Musical Notes and Their Frequencies (Part II)

Frequencies in Arduino

Students also learned how Arduino generates sound by sending electrical pulses at specific frequencies, which the buzzer converts into audible tones—strengthening the connection between digital electronics and acoustic perception.

After converting the notes into frequencies, they proceeded to program the melody in Arduino, as illustrated in Fig. 4.7.

```
int song1[] = {392, 392, 440, 392, 523, 494};      // Happy birthday to you...
int song2[] = {392, 392, 440, 392, 587, 523, 523}; // On this special day...
```

Figure 4.7: Part I and II in Arduino Code

Questionnaire

At the end of the lesson, students completed a questionnaire evaluating:

- their understanding of the content,
- their perception of the EcoMusic system,
- and their ability to relate musical and technological concepts.

Conclusion

The lesson 2 offered a more technical and integrative experience. It introduced the conceptual foundations of EcoMusic, explained its physical construction and programming logic, and expanded students' understanding of musical elements such as notes, frequencies, octaves, and MIDI. These concepts were then applied through the analysis of the song "Happy Birthday" and through hands-on experimentation with the EcoMusic device. Finally, all materials used and produced in the classes are available in the GitHub repository: `https://github.com/Natalnet/EcoMusic`

Chapter 5

Experiments and Results

The experiments and results presented in this section refer to the classroom implementation of the EcoMusic system, in which data were collected directly from students and the participating teacher. This stage of the research enabled the evaluation of EcoMusic in an authentic educational environment, allowing the analysis of how the integration of musicalization within educational robotics influences student engagement, participation, and understanding of musical and technological concepts. The feedback gathered provides concrete and meaningful evidence of the pedagogical potential of this interdisciplinary approach, supporting future refinements and broader applications of the project.

5.1 Experiments

As this project involved human participants, it was submitted to the Brazilian Research Ethics Committee, in accordance with national ethical guidelines. This submission ensured that all research procedures respected informed consent, confidentiality, participant safety, and the physical and psychological integrity of those involved.

The experimental activities of this study were conducted exclusively at Escola Municipal Professora Josefa Botelho, located in Natal/RN. This school was selected due to its established educational robotics program and its suitability for implementing the proposed EcoMusic activities within an authentic classroom context.

A total of 25 elementary school students participated in the research, distributed across three different classes. The intervention consisted of two instructional sessions of approximately two hours each, integrated into the school's regular robotics schedule. During these sessions, students engaged in musicalization activities mediated by the EcoMusic device, allowing for the collection of qualitative and quantitative data relevant to the study.

Due to the exploratory nature of the research and its implementation in a single school context, no formal control group was established at this stage. The participant group included only students enrolled in the arts subject, as these students already had music classes at Escola Municipal Professora Josefa Botelho. The students, aged approximately 11 to 17 years, were selected based on class availability and schedule coordination with one of the school's art teachers, who also acted as a pedagogical mediator during the activities. The implementation was additionally supported by the school's robotics intern.

In the absence of a control group, the feedback provided by the art teacher served as a qualitative comparative reference, grounded in the teacher's prior teaching experience in traditional music classes. The teacher's observations regarding student engagement, participation, and learning during the EcoMusic sessions were contrasted with patterns commonly observed in regular classes, offering contextual insights into the effects of the proposed intervention.

Data collection involved administering printed and digital questionnaires to students at the conclusion of the activities, as well as a specific questionnaire addressed to the art teacher. The student questionnaires focused on motivation, satisfaction, and perceived learning related to the EcoMusic activities. Teacher feedback complemented the student data by providing reflective observations on classroom dynamics, levels of student interest, and the pedagogical relevance of integrating musicalization with educational robotics.

5.2 Results

EcoMusic is designed as a custom cardboard speaker box, allowing students to assemble it creatively with various colors and shapes using painting or prints, as demonstrated in this study. The project design took into account the speaker's shape, resembling an eye.

Assembly and functional testing

The EcoMusic project was assembled as illustrated in Figure 5.1. Functional tests were performed that included voltage and current measurements, and the programmed code was uploaded to the Arduino. During testing, it was verified that EcoMusic played a melody when pressing the first button (white) and another melody when pressing the second button (yellow), as programmed.

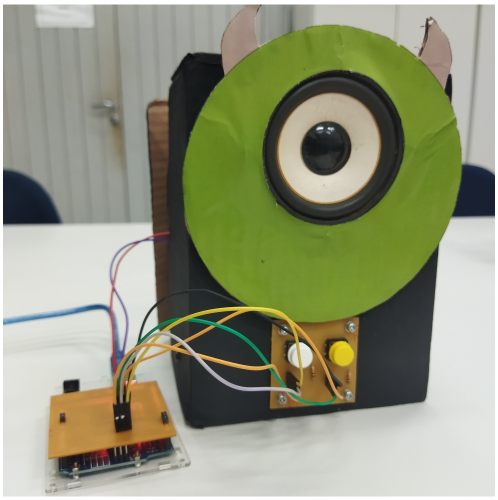

Figure 5.1: Picture of the assembly of the EcoMusic Robot.

5.3 Results of Applying EcoMusic in the Classroom

The EcoMusic project was implemented in the classroom over two instructional sessions in which students explored the integration of musical concepts with educational robotics. These activities enabled the 25 participating elementary school students to work with sound creation, frequency conversion, and the programming of musical outputs using the EcoMusic device.

To evaluate the learning experience, two questionnaires were administered at the end of the activities. The first, directed to all 25 students, consisted of 10 questions designed to assess their engagement, understanding, and perceptions regarding the integration of music and robotics. The second questionnaire, composed of 18 questions, was completed by the teacher responsible for the three participating classes, who has experience teaching music at the elementary school level. This instrument aimed to gather insights into the pedagogical applicability, classroom dynamics, and perceived effectiveness of EcoMusic.

5.3.1 Analysis of student questionnaires

Based on the questionnaire administered (Appendix A)., the following results were obtained, corresponding to the responses provided by the participants.

1. Have you had contact with robotics before this activity?

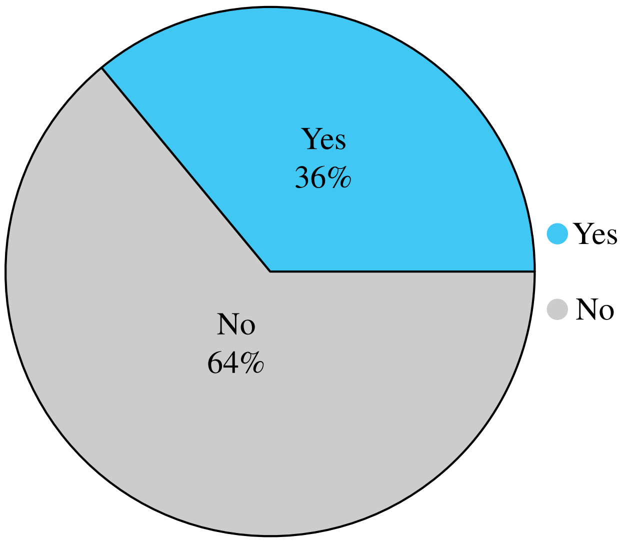

Figure 5.2: Distribution of responses to Question 1 — Previous contact with robotics: Yes (36%) and No (64%).

As shown in Figure 5.2, most students (64%) reported having no prior contact with robotics. This result indicates that the majority of participants approached the activity with little to no previous experience, reinforcing the importance of adopting introductory and accessible instructional strategies. Conversely, the 36% of students who reported prior exposure to robotics may have acted as informal peer-support sources during the activities, contributing to collaborative learning dynamics.

2. Do you like music?

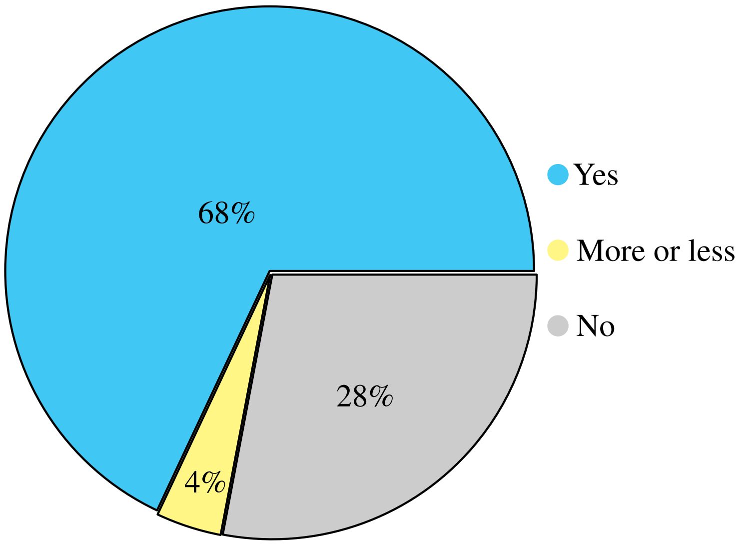

Figure 5.3: Distribution of responses to Question 2 — Students' interest in music: Yes (68%), More or less (4%), No (28%).

As shown in Figure 5.3, a substantial majority of students (68%) stated that they enjoy music, which supports the pedagogical choice of integrating musical activities into robotics lessons. Although 28% indicated that they do not particularly like music, this does not appear to have hindered engagement, as subsequent responses suggest that the integration of musical and technological elements still captured their interest. The low percentage of "More or less" responses (4%) indicates that students' opinions tended to be polarized.

3. Did you find it easy or difficult to use EcoMusic?

As shown in Figure 5.4, the majority of students (72%) considered the device "easy" or "very easy" to use, demonstrating that the EcoMusic interface was accessible

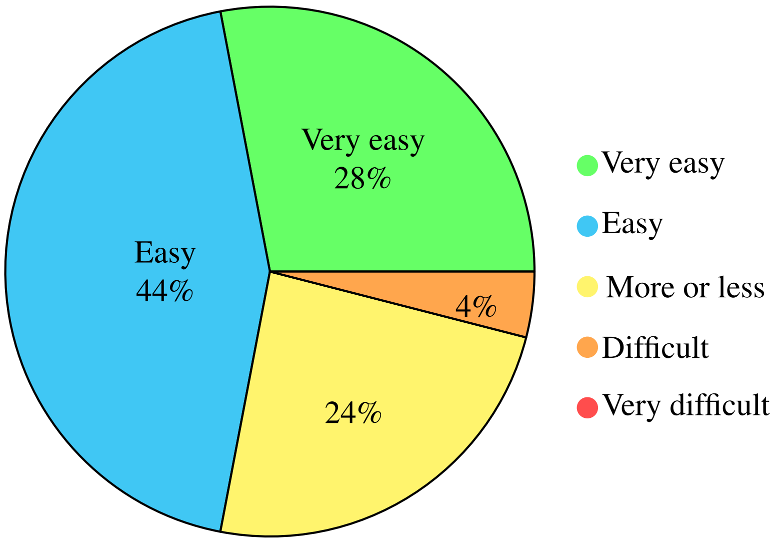

Figure 5.4: Distribution of responses to Question 3 — Perceived ease of use of EcoMusic (Very easy, Easy, More or less, Difficult, Very difficult).

and age-appropriate. Only a small portion (4%) found the activity difficult, and none considered it very difficult, suggesting that the balance between technological complexity and pedagogical scaffolding was adequate. The 24% who answered "More or less" indicate an intermediate group that may benefit from additional guided practice.

4. Did you have fun while learning with EcoMusic?

   As shown in Figure 5.5, most students (52%) reported having fun, and 36% indicated a moderate level of enjoyment. This combined 88% positive/neutral outcome suggests that EcoMusic is effective in promoting engagement, even among students who previously stated they did not like music. The 12% who did not enjoy the activity may reflect individual learning preferences or challenges related to technology use.

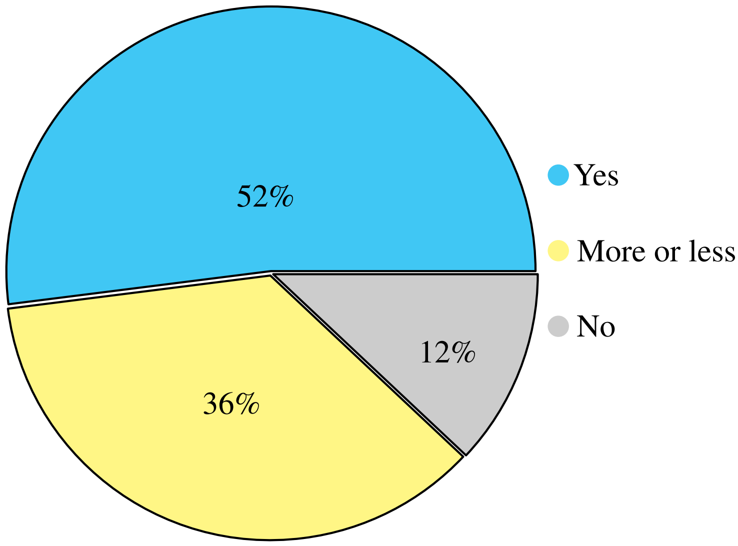

Figure 5.5: Distribution of responses to Question 4 — Enjoyment of learning with EcoMusic: Yes (52%), More or less (36%), No (12%).

5. Did EcoMusic help you better understand how music works (sounds, rhythms, notes, melodies, timbre, and silence)?

   As shown in Figure 5.6, a majority of students (56%) affirmed that EcoMusic improved their understanding of musical concepts such as sound, rhythm, notes, melody, timbre, and silence. Additionally, 36% reported partial understanding, suggesting that the hands-on experience with frequency conversion and musical interpretation successfully supported conceptual learning. Only 8% stated that the activity did not help, indicating broad overall pedagogical effectiveness.

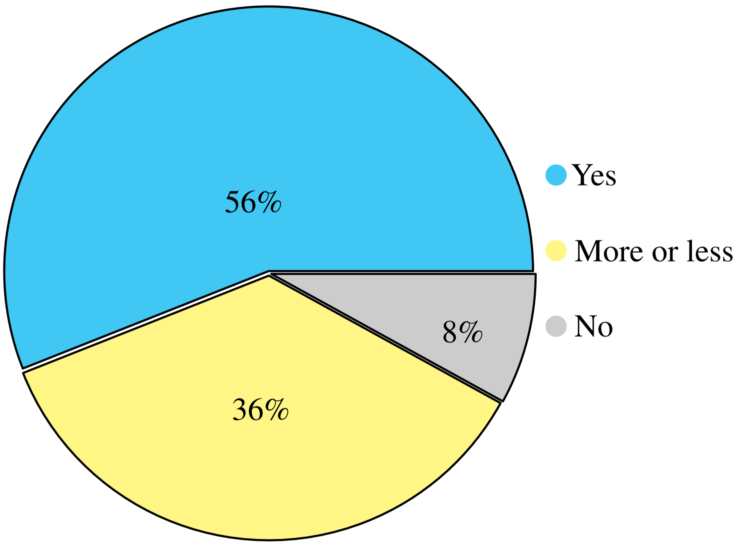

Figure 5.6: Distribution of responses to Question 5 — Understanding of how music works using EcoMusic: Yes (56%), More or less (36%), No (8%).

6. Did the functioning of the instruments made from recycled materials catch your attention?

   As shown in Figure 5.7, the use of instruments built from recycled materials captured the attention of most students (52%). This result aligns with the ecological dimension of the EcoMusic project and shows that sustainability-based technological artifacts can encourage interest. The 36% who indicated moderate attention still suggest that the integration of recyclables is pedagogically relevant, although improvements in aesthetic or interactive elements could further enhance engagement.

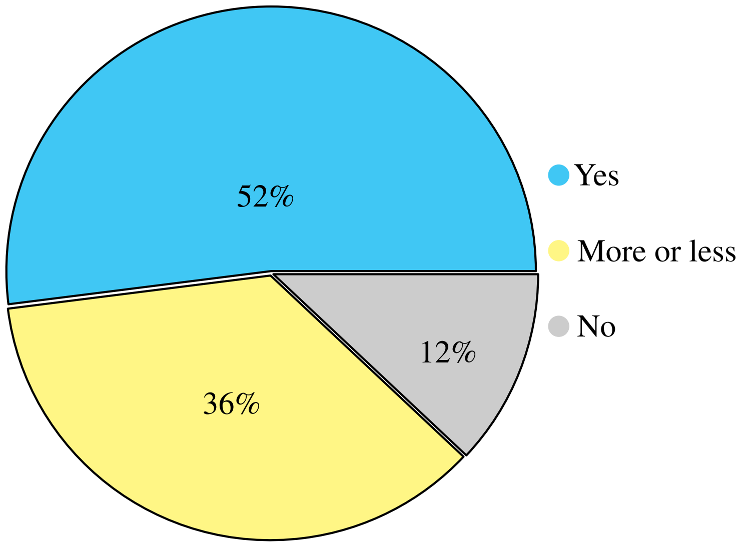

Figure 5.7: Distribution of responses to Question 6 — Students' interest in the functioning of instruments made from recycled materials: Yes (52%), More or less (36%), No (12%).

7. On a scale from 1 (little) to 5 (a lot), how much did the robot help you understand what was taught?

   As shown in Figure 5.8, responses show a progressive increase from the lower to the higher end of the scale. Scores 4 and 5 together represent the largest group (14 students), indicating that more than half of the participants considered the robot highly supportive of their learning. The very small number of students who selected 1 or 2 (6 in total) suggests that although some learners experienced difficulty, the majority viewed the robot as a meaningful explanatory tool.

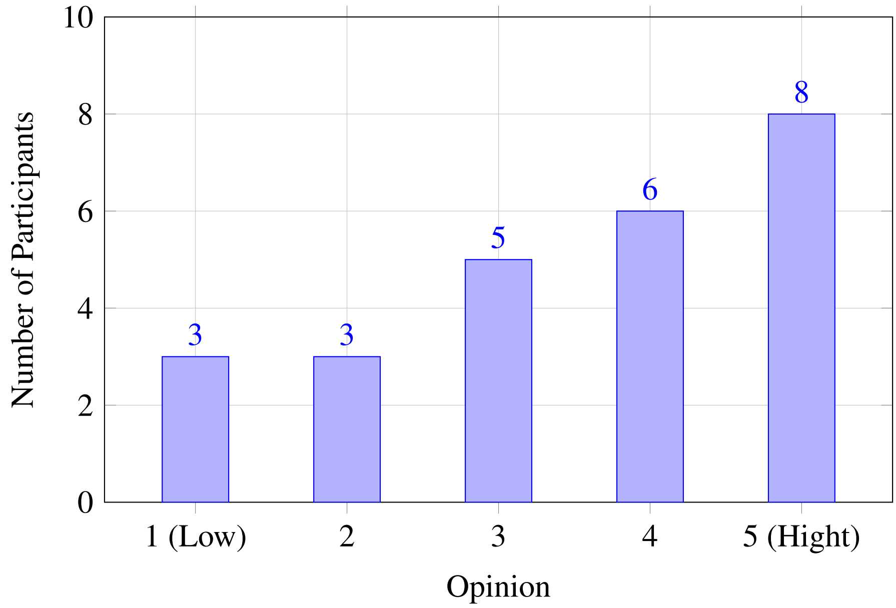

Figure 5.8: Distribution of responses to Question 7 — Perceived level of support provided by the robot in understanding the content (scale from 1 to 5).

8. Do you think that using robotics and music together helps you learn in a different way?

   As shown in Figure 5.9, an expressive 72% of the students recognized that combining robotics and music offered a different and beneficial learning experience. This validates the interdisciplinary approach proposed by EcoMusic. Only 8% reported no perceived difference, reinforcing the general acceptance of multimodal learning environments where creativity, technology, and sound interact.

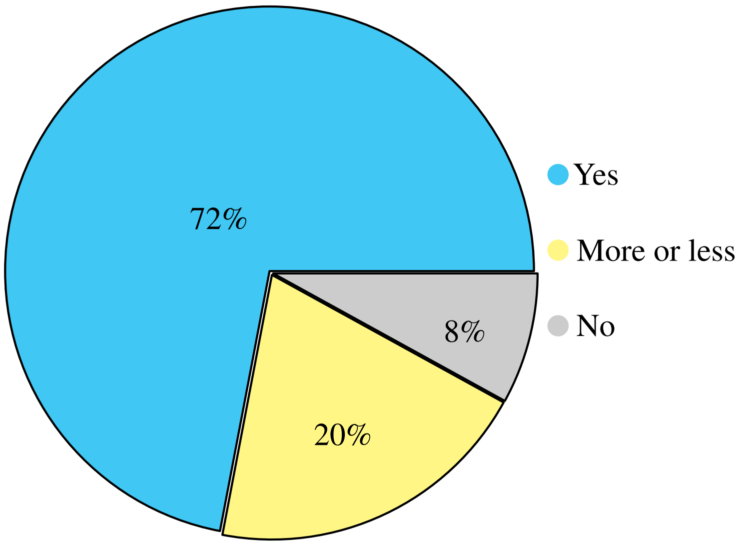

Figure 5.9: Distribution of responses to Question 8 — Perception of learning in a different way through the integration of robotics and music: Yes (72%), More or less (20%), No (8%).

9. What new things did you learn with EcoMusic?

   As shown in Figure 5.10, the analysis of the 25 open-ended student responses enabled the identification of recurring learning categories. The largest proportion of students (40.91%) explicitly reported learning related to musical concepts—such as notes, frequencies, rhythm, and the functioning of sound—indicating that EcoMusic contributed to a concrete understanding of fundamental musical elements.

   Another relevant group of responses (18.18%) consisted of statements such as "I learned many things," which reflect a generalized perception of learning and novelty. Although this type of response is inherently abstract and may be influenced by response convenience or social desirability—particularly in school-based questionnaires—it was retained as an analytical category to acknowledge students' subjective perception of learning. However, these responses were treated separately from those that demonstrated explicit conceptual understanding.

   To clarify the distribution of learning perceptions, the open-ended responses were grouped into the following categories:

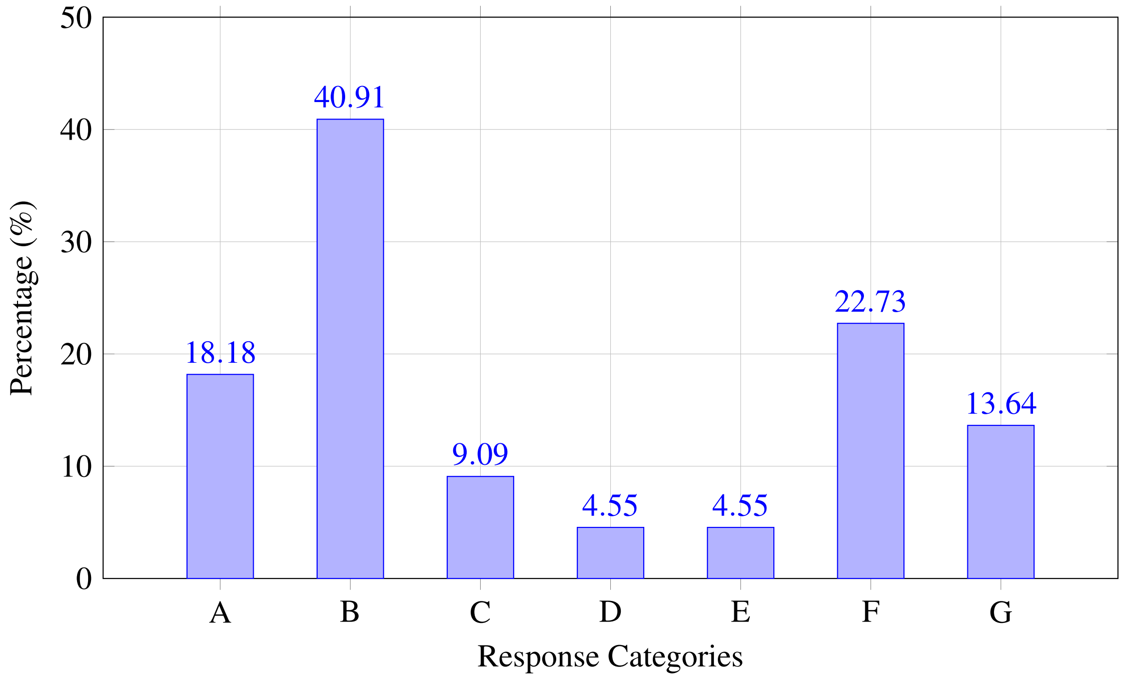

Figure 5.10: Distribution of categorized responses to Question 9 — New things learned with EcoMusic (student open-ended responses).

- **Category A — Learned many things** (18.18%)
- **Category B — Music theory / notes, frequencies, how music works** (40.91%)
- **Category C — Rhythm / robot music** (9.09%)
- **Category D — General learning (non-specific)** (4.55%)
- **Category E — Use of recyclables** (4.55%)
- **Category F — Learned little or nothing** (22.73%)
- **Category G — No answer** (13.64%)

A smaller portion of students (9.09%) highlighted learning specifically related to rhythm and the robot's musical behavior. Additionally, two smaller groups (4.55% each) reported other types of learning: one referred to general, non-specific learning, indicating broadly framed perceptions without clearly defined content, while the other emphasized learning related to the use of recyclable materials, reflecting engagement with the ecological dimension of the project.

Conversely, 22.73% of the participants stated that they learned little or nothing, suggesting differences in individual engagement, levels of abstraction, or difficulties in connecting the activities to prior knowledge. Additionally, 13.64% of students did not respond to the open-ended question, a pattern commonly observed in educational questionnaires with younger learners.

Overall, the qualitative findings complement the quantitative results by revealing both explicit conceptual gains and more diffuse perceptions of learning. While some responses indicate clearly articulated musical understanding, others point to subjective impressions of discovery or novelty, highlighting the importance of combining open-ended data with structured instruments to achieve a more nuanced interpretation of learning outcomes.

10. What do you think could be improved?

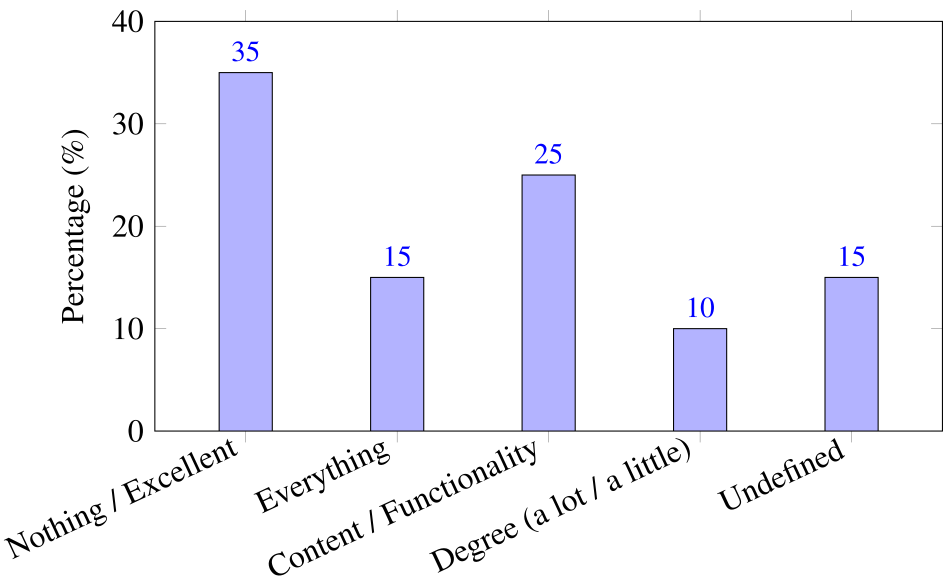

Figure 5.11: Distribution of responses to Question 10 — Students' perceptions of possible improvements to EcoMusic.

As shown in Figure 5.11, most students (35%) responded that nothing needed improvement, suggesting general satisfaction with the activity. However, 25% pointed to content or functionality aspects that could be refined, indicating opportunities to adjust explanations, add examples, or improve device stability. Additionally:

- 15% suggested improvements "in everything," which may reflect a desire for more variety or depth in activities.
- 10% commented on the degree of difficulty, implying that hands-on tasks could be differentiated for different learning levels.
- 15% provided undefined or unclear responses.

Overall, the suggestions highlight that while the activity was well received, enhancements in the instructional design could further support learning for diverse student profiles.

5.3.2 Analysis of Teacher Questionnaires

To complement the analysis of student learning, a questionnaire consisting of 18 questions was administered to the teacher responsible for the participating classes (Appendix B).

1. Years of experience as an arts/music teacher?
   The teacher reported having more than seven years of professional experience in arts and music education. This extensive experience suggests familiarity with different pedagogical approaches, classroom dynamics, and curriculum demands, providing a solid basis for evaluating innovative proposals such as EcoMusic.
2. Grade level/segment you teach?
   The teacher indicated working in elementary education, teaching music as part of the broader Arts curriculum. This context is particularly relevant, as it aligns with the target audience of the EcoMusic proposal and supports the analysis of its applicability and pedagogical effectiveness in early and middle school settings.
3. On a scale from 1 (low) to 5 (high), how would you evaluate the overall engagement of students in traditional music classes?

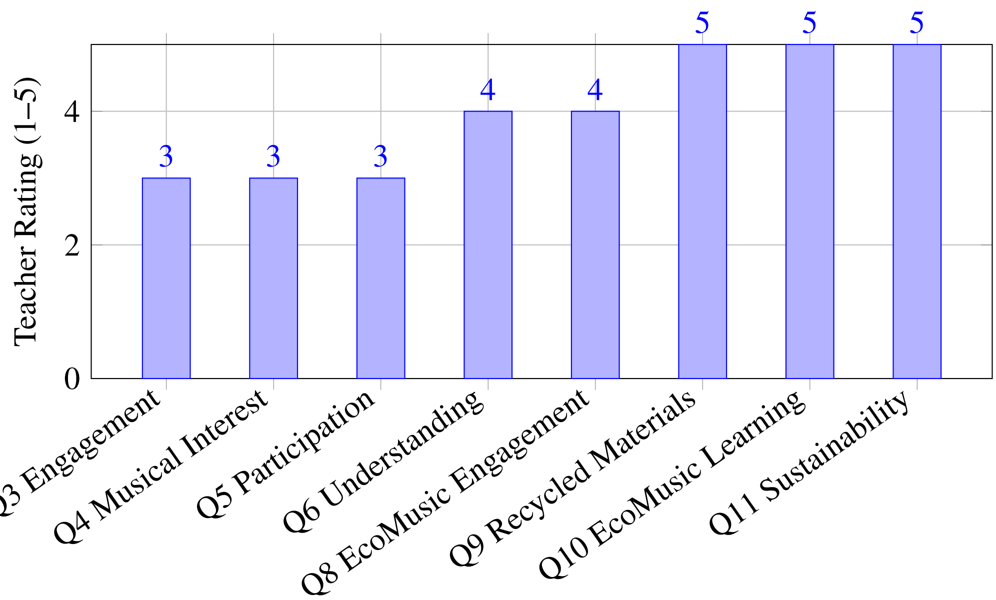

Figure 5.12: Quantitative summary of teacher ratings for the EcoMusic classroom implementation.

As shown in Figure 5.12, the teacher rated student engagement in traditional music classes as **3 out of 5**, indicating a moderate level of participation and interest. This result suggests that, although students are somewhat engaged, there is considerable room for improvement in terms of motivation, involvement, and enthusiasm during conventional music lessons. This baseline assessment serves as a reference for comparison with the EcoMusic intervention.

4. How would you rate students' interest in exploring sounds, rhythms, and instruments?

   According to Figure 5.12, students' interest in exploring sounds, rhythms, and musical instruments was rated at level **3**, corresponding to a moderate degree of curiosity and engagement. While students showed willingness to participate, the result indicates that traditional approaches may not consistently stimulate deeper musical exploration or creativity.

5. How would you describe students' active participation (experimenting, asking questions, testing instruments)?

As shown in Figure 5.12, active participation was also rated as **3 out of 5**. This suggests that students demonstrated a reasonable level of involvement in experimenting and interacting during activities, but that participation was not consistently high. These findings reinforce the need for more interactive and hands-on strategies to foster stronger engagement.

6. In your perception, how much do traditional music classes help students understand basic musical concepts?

   Figure 5.12 indicates a score of **4**, suggesting that traditional music classes are generally effective in supporting students' understanding of basic musical concepts, such as rhythm, pitch, and melody. According to the teacher, conventional instruction adequately conveys foundational knowledge; however, the lack of technological or interactive elements may limit deeper comprehension or sustained motivation.

7. Main challenges observed in these classes (or with these students):

   This question was addressed through a qualitative, open-ended response and is therefore not represented in Figure 5.12.

   > *"The 4th grade class is very enthusiastic about musical instruments and music education, while the AVEX (mixed class from 6th to 9th grade) class and the 6th grade C class don't show as much enthusiasm for experimenting with sounds and instruments. Perhaps due to shyness, fear of judgment, or issues related to adolescence."*

   According to the teacher, the main challenges relate to differences in engagement across age groups. While younger students showed high enthusiasm and openness to experimentation, older students exhibited lower participation levels, possibly due to shyness, fear of peer judgment, and developmental factors associated with adolescence. These observations highlight the importance of differentiated pedagogical strategies to support engagement among older learners.

Observations on the Intervention Classes (With EcoMusic)

8. The level of student engagement while using EcoMusic was:

   As illustrated in Figure 5.12, student engagement during EcoMusic activities was rated as **4 out of 5**, indicating a high level of participation and interest. Compared to traditional classes, the integration of technology and musical experimentation clearly enhanced student involvement, curiosity, and motivation.

9. Did the use of robotics and recyclable materials increase student interest?

   Figure 5.12 shows a maximum score of **5**, indicating that the use of robotics and recycled materials significantly increased student interest. This result suggests that hands-on experimentation combined with ecological awareness strongly contributes to engagement and curiosity in music education contexts.

10. Did students demonstrate better understanding of musical elements (rhythm, intensity, timbre, etc.) with EcoMusic?

    According to Figure 5.12, the teacher assigned a score of **5 out of 5**, indicating a substantial improvement in students' understanding of musical elements when using EcoMusic. The association between abstract musical concepts and tangible, interactive feedback appears to have facilitated learning and conceptual clarity.

11. In your perception, did EcoMusic contribute to connecting music and sustainability?

    As shown in Figure 5.12, a score of **5** indicates that EcoMusic was perceived as highly effective in linking musical learning with sustainability concepts. The use of recycled materials reinforced ecological awareness in an authentic and pedagogically meaningful way.

12. Main difficulties or limitations observed when using EcoMusic:

    The teacher did not report any specific difficulties or limitations related to the use of EcoMusic. As this question did not yield quantitative data, it is not represented in Figure 5.12. Consequently, no challenges in this dimension could be identified based on the available responses.

Comparative Analysis Between Groups (Control vs. EcoMusic)

13. Student participation in classes with EcoMusic compared to classes without EcoMusic:

    The teacher evaluated the level of student participation in the EcoMusic classes as **"equally participatory"** compared to the traditional music classes. The questionnaire offered three possible options—*less participative*, *equally participative*, and *more participative*—and the teacher explicitly selected the middle alternative.

    This result indicates that, although EcoMusic introduced new elements such as technological exploration, sound experimentation, and the integration of recycled materials, the overall level of student engagement did not differ significantly from what is typically observed in the teacher's regular music lessons.

    Several interpretations may help explain this outcome:

    - **Students were already accustomed to the teacher's music classes**, which may have contributed to stable participation across both the control (traditional) and intervention (EcoMusic) conditions.
    - **EcoMusic did not reduce student engagement**, demonstrating that incorporating robotics and musical experimentation did not create barriers or discomfort for learners.

    Overall, the teacher's response suggests that EcoMusic maintained a consistent level of student participation when compared to traditional classes. This stability reinforces the feasibility of integrating musicalized educational robotics into the curriculum, as the approach does not negatively impact classroom engagement. Additionally, future implementations with longer duration or iterative cycles may allow potential gains in participation and enthusiasm to emerge more clearly.

14. Student interest in music in classes with EcoMusic:

The teacher evaluated the level of student interest in music during the EcoMusic classes as **“the same level of interest”** compared to traditional music lessons. Among the three available options—lower interest, same level of interest, and greater interest—the teacher selected the second one.

This evaluation indicates that, although EcoMusic introduced new elements such as technological experimentation, the use of recycled materials, and the integration of robotics into musical learning, these innovations did not significantly increase or decrease students’ interest in music.

Several interpretations can be drawn from this result:

- **EcoMusic maintained the students’ existing interest in music**, demonstrating that the approach did not diminish motivation or engagement with musical content.
- **Students may already possess a stable interest in music**, which remained consistent regardless of the inclusion of technological tools.
- **The effect of EcoMusic on interest may require prolonged exposure**, as a two-lesson intervention might not be sufficient to alter students’ emotional or motivational connection to music.

Overall, the teacher’s response suggests that EcoMusic is a **neutral but positive pedagogical tool**: it sustains students’ interest in music while introducing new ways to interact with sound, rhythm, and musical concepts. Although it did not increase interest in the short term, it also did not cause disengagement, indicating that the method is pedagogically safe and potentially impactful with longer or more frequent implementation cycles.

15. Understanding of musical concepts in classes with EcoMusic:

Understanding of Musical Concepts in Classes with EcoMusic

For this question, the teacher had three response options:

- *Prejudiced learning*
- *Did not change learning*
- *Facilitated learning*

The teacher selected the option **"Facilitated learning"**. This response indicates that the use of EcoMusic positively contributed to students' understanding of fundamental musical concepts, such as rhythm, intensity, timbre, frequency, and melody.
According to the teacher's perception, EcoMusic provided concrete and multi-sensory experiences that helped students better grasp abstract musical principles. By visualizing, manipulating, and hearing the results of frequency conversion and sound generation, learners were able to connect theoretical knowledge with practical experimentation.
This result reinforces the pedagogical value of EcoMusic as a tool that supports musical learning through hands-on interaction. It suggests that integrating robotics and musicalization can strengthen conceptual comprehension, making music more accessible and meaningful for students.

Open-Ended Responses

16. Main pedagogical contributions of EcoMusic:

Main pedagogical contributions of EcoMusic

The teacher identified several pedagogical contributions resulting from the use of EcoMusic in the classroom. According to the response, EcoMusic stimulated both technological and musical curiosity among students. The teacher emphasized that:

> "I believe that EcoMusic brought technological as well as musical curiosities. The fact that the child can create something is already fantastic in itself."

This perspective highlights two key contributions:

- **Stimulation of curiosity:** EcoMusic encouraged students to explore new concepts, tools, and processes, promoting deeper interest in both music and technology.
- **Creative empowerment:** Allowing students to create their own musical outputs strengthened their sense of autonomy and engagement, reinforcing the educational value of hands-on, project-based learning.

Overall, the teacher feedback suggests that EcoMusic supports an enriched learning environment, fostering creativity, interdisciplinary exploration, and active participation.

17. Aspects that should be improved: The teacher replied:

> "The frequencies could be conventional to provide better tuning for EcoMusic."

This perspective highlights two key contributions:

- **Main pedagogical contributions of EcoMusic**

  According to the teacher, EcoMusic generated meaningful pedagogical benefits by stimulating both technological and musical curiosity among students. The teacher highlighted that allowing children to *create something of their own* is intrinsically valuable, as it fosters autonomy, creativity, and engagement. The hands-on exploration of sound, frequency, and musical structure strengthened the interdisciplinary character of EcoMusic, demonstrating its potential as a tool that promotes investigation, experimentation, and authorship in learning.

- **Aspects that should be improved**

  The teacher noted that one important aspect to refine is EcoMusic's tuning accuracy. Specifically, they suggested adopting *conventional frequency stan-*

dards to improve the device's pitch alignment. Such an adjustment would enhance the clarity and musical precision of the sounds produced, making the experience more coherent with traditional musical expectations and supporting students in developing a more accurate understanding of pitch relationships.

18. Additional comments about the experience: The teacher was asked whether they would like to provide any additional comments regarding the experience with EcoMusic. However, **no response was provided** to this open-ended question. The absence of feedback may indicate that the teacher had no further observations beyond those already discussed, or simply chose not to add additional remarks at this stage of the evaluation.

5.3.3 Final Analysis of the EcoMusic Classroom Implementation

The application of EcoMusic in the classroom generated a wide range of informative feedback from both students and the teacher, providing a comprehensive view of its pedagogical impact. Overall, the results demonstrate that EcoMusic is an accessible, engaging, and conceptually meaningful tool for integrating music and educational robotics in elementary education.

From the student questionnaires, it was observed that most participants had no prior experience with robotics, yet they quickly adapted to the activities and perceived the EcoMusic device as easy to use. Levels of enjoyment and engagement were generally positive, with a significant majority reporting that the activities were fun and helped them better understand musical concepts such as rhythm, pitch, timbre, and the functioning of sound. The interdisciplinary combination of music, technology, and sustainability was particularly well received, with many students expressing curiosity about the recycled-material instruments and identifying meaningful learning related to musical theory and the behavior of the robot.

A closer examination of students' perceptions regarding conceptual understanding reveals consistent results across different questionnaire items. In Question 5, most students (56%) stated that EcoMusic helped them better understand how music works, while an additional 36% reported partial improvement. These responses suggest that the hands-on interaction with the robot supported the comprehension of abstract musical concepts, even when learning gains were perceived as gradual or incomplete. This finding is reinforced by Question 7, in which students rated the degree to which the robot helped them understand the content. The concentration of responses at the higher end of the scale—particularly scores 4 and 5, which together represented more than half of the participants—indicates that EcoMusic was widely perceived as a meaningful learning facilitator, with relatively few students reporting limited benefit.

The categorization of open-ended responses further supports these findings, revealing that 40.91% of students learned specific musical concepts, while 18.18% reported broad, general learning. Although a smaller portion (22.73%) indicated learning little or nothing, this outcome is common in open-ended questions and may reflect individual differences in attention, engagement, or comprehension. Importantly, approximately 72% of participants recognized that the integration of robotics and music offered a new way of learning, highlighting the educational value of interdisciplinary and experiential approaches.

Complementing the student feedback, the teacher's responses provided an experienced and contextual perspective on the intervention. In the absence of a control group, the teacher's evaluation was based on prior teaching experience in traditional music classes. According to the instructor, student participation and interest during the EcoMusic sessions were comparable to those typically observed in regular lessons, indicating that the introduction of the technological artifact did not hinder engagement. More notably, in Question 8, the teacher assigned the highest possible score (5/5) to students' improvement in understanding musical elements when using EcoMusic. The teacher emphasized that associating musical concepts with visual, tactile, and auditory feedback facilitated the comprehension of rhythm, pitch, intensity, and timbre.

In addition to student learning outcomes, the EcoMusic implementation also revealed relevant implications for the educator's role in the classroom. From the teacher's perspective, the device functioned as a pedagogical support tool that facilitated the explanation of musical concepts through interactive and multisensory demonstrations. In this sense, EcoMusic can be understood as a complementary educational resource that supports teaching practices without replacing direct instruction, offering potential benefits in introductory music education contexts by assisting educators in addressing diverse learning paces while maintaining pedagogical control and student engagement.

Collectively, the convergence between students' self-reported learning gains and the teacher's professional assessment suggests that EcoMusic functioned as an effective pedagogical support for musical understanding. Although causal claims cannot be made due to the absence of a control group, the alignment between learner perceptions and teacher observations provides qualitative evidence of the educational potential of the proposed approach.

It is important to emphasize that the analysis is based on a limited number of instructional sessions, which may have amplified a novelty effect. Since the EcoMusic activities were conducted over only two meetings, students' motivation and curiosity may have been influenced by the introduction of an unfamiliar technological artifact rather than by sustained pedagogical impact. This factor represents a common limitation in short-term classroom interventions and should be considered when interpreting the engagement-related results.

However, given the limited number of instructional sessions and the size of the participant group, these findings should be interpreted as preliminary. While the evidence points to positive tendencies in engagement, conceptual understanding, and interdisciplinary learning, further implementations with extended duration and broader samples are necessary to more robustly assess the educational impact of EcoMusic. Within these constraints, the project emerges as a promising starting point for integrating musicalization and educational robotics in classroom contexts.

Chapter 6

Conclusion

The present study investigated the effects and effectiveness of incorporating musicalization into the teaching of educational robotics through the EcoMusic project. The classroom implementation involved two instructional sessions in which 25 elementary school students explored musical concepts using robotics, frequency conversion, and sound experimentation. The subsequent analysis of student and teacher questionnaires provided a comprehensive understanding of how this interdisciplinary approach influenced engagement, learning, and classroom dynamics.

The results obtained indicate that EcoMusic has enriched the learning process by promoting curiosity, active participation, and conceptual understanding. A great part of the students reported positive experiences: 52% had fun during the activities, 56% felt that EcoMusic helped them understand musical elements, and 72% recognized that combining robotics with music offered a different and engaging learning experience. Additionally, more than half of the students (scores 4 and 5) indicated that the robot significantly supported their understanding of the content taught.

The open ended responses reinforced these quantitative findings. Almost half of the students (40.91%) reported learning related to musical theory—notes, frequencies, rhythm, and sound functioning—demonstrating meaningful conceptual gains. Another 18.18% indicated that they "learned many things," reflecting a broad sense of discovery. Small groups highlighted learning about rhythm (9.09%) and recyclables (4.55%), while

22.73% reported learning little or nothing, pointing to the presence of individual learning differences and possible difficulties among a minority of students.

Teacher feedback also provided important feedback. According to the instructor, EcoMusic facilitated the understanding of musical concepts and sparked technological and musical curiosity, especially due to the hands-on nature of sound creation and experimentation. However, the teacher pointed out some technical refinements that are still necessary, such as adjusting the device to use conventional musical frequencies to improve pitch accuracy. Interestingly, despite the novelty of the approach, the teacher rated student participation and interest in EcoMusic classes as being at the *same level* as in traditional music classes—having chosen this option among three alternatives—suggesting that students maintained stable engagement regardless of the format.

The study also highlighted challenges related to classroom differences. Younger students showed high enthusiasm for instruments and musical experimentation, whereas older students demonstrated more restraint, possibly due to adolescence-related factors such as shyness or fear of judgment. These observations underscore the importance of adapting activities to developmental stages to maximize participation.

Taken together, the results confirm the pedagogical potential of integrating music into educational robotics. EcoMusic proved to be an engaging tool that supports conceptual learning, creativity, and interdisciplinary thinking, while also introducing sustainability through the use of recyclable materials. At the same time, the findings reveal areas for improvement, particularly in tuning precision and differentiated support for students who experienced difficulty.

In future implementations, extending the duration of activities, refining the technological components, and adapting tasks to different age groups may enhance the impact of the approach. Additionally, further comparison with previous studies on musicalized robotics may provide deeper insights into how music functions as a complementary pedagogical resource capable of enhancing participation, motivation, and understanding.

Ultimately, this research contributes to the field of educational robotics by demonstrating that musicalization represents a viable and promising avenue to enrich learning, promote inclusion, and foster creativity within technology-integrated educational environments.

Bibliography

Ahijado, Sonsoles Ramos; Nicolas, Ana Maria Botella (2019), ‘Enseñanza-aprendizaje músico-matemático utilizando robótica educativa’, *EFT: Educação, Formação & Tecnologias* **8**(3).

Andrade, Jose Lindenberg De (2023), Projeto de fabricação de um kit de robótica educacional multidisciplinar adequado para a base nacional comum curricular (bncc), Trabalho de conclusão de curso de engenharia mecatrônica, Universidade Federal do Rio Grande do Norte, Natal, RN.

Andrade, José Lindenberg De, Márcio Valério de Araújo, Pablo Javier Alsina & Luiz M. G. Gonçalves (2024), ‘Ecomusic: An ecological musical robot’, *2024 Brazilian Symposium on Robotics (SBR): Workshop on Robotics in Education (WRE). IEEE* **1**(1), 191–196.

Antunes et al., Sabrina F. (2017), ‘Robótica livre como alternativa didática para a aprendizagem de música’, *CINTED-UFRGS* **15**(2).

Bamberger, Jeanne (1975), The development of musical intelligence I: Strategies for representing simple rhythms, LOGO Memo 19, MIT Artificial Intelligence Laboratory, Cambridge, MA.

Banzi, Massimo & Michael Shiloh (2022), *Getting Started with Arduino*, 5ª edição, Maker Media, San Francisco.

Bdeir, Ayah (2014), ‘Electronics as material: Littlebits’, *Interactions* **21**(1), 14–17.

Benitti, Fabiane Barreto Vavassori (2012), 'Exploring the educational potential of robotics in schools: A systematic review', *Computers & Education* **58**(3), 978–988.

Blasco-Magraner, José Salvador, Gloria Bernabe-Valero, Pablo Marín-Liébana & Carmen Moret-Tatay (2021), 'Effects of the educational use of music on 3- to 12-year-old children's emotional development: A systematic review', *International Journal of Environmental Research and Public Health* **18**(7), 3668.

Blikstein, Paulo (2018), Digital fabrication and making in education: The democratization of invention, *em* 'Proceedings of the FabLearn 2018 Conference', Stanford University Press, Stanford.

CLAVEDEC (2023), 'Parabéns pra você | partitura colorida', `https://clavedec.com.br/2023/02/parabens-pra-voce-partitura-colorida/`. Accessed: 07 Nov. 2025.

Cochrane, Tom, Bernardino Fantini & Klaus R. Scherer, eds. (2013), *The Emotional Power of Music: Multidisciplinary perspectives on musical arousal, expression, and social control*, Oxford University Press.

COUTO, R (2019*a*), 'Músicas para arduino', Available online at `https://dragaosemchama.com/2019/02/musicas-para-arduino/`. Acesso em: 15 nov. 2023.

COUTO, R (2019*b*), 'Músicas para arduino a partir da partitura.', `https://dragaosemchama.com/2019/04/musicas-para-arduino-a-partir-da-partitura/`. Acesso em: 15 nov. 2023.

Feng, Huanghao, Mohammad H Mahoor & Francesca Dino (2022), 'A music-therapy robotic platform for children with autism: A pilot study', *Frontiers in Robotics and AI* **9**, 855819.

García-Tudela, Pedro Antonio & José-Antonio Marín-Marín (2023), 'Use of arduino in primary education: A systematic review', *Education Sciences* **13**(2), 134.

Hallam, Susan (2010), 'The power of music: Its impact on the intellectual, social and personal development of children and young people', *International Journal of Music Education* **28**, 269–289.

Hodges, Donald (2019), *Music in the Human Experience: An Introduction to Music Psychology*, Routledge - Taylor & Francis Group.

LEGO Education (2020), *LEGO SPIKE Prime User Guide*, LEGO Group, Billund.

Machado, Adriana, Juliana Câmara & Vicente Willians (2024), 'Robótica educacional: Desenvolvendo competências para o século xxi', *III Congresso sobre Tecnologias na Educação* pp. 215–226.

MarioWiki (2024), 'Kenta nagata'. Accessed: 2024-08-05.

Martinez-Roig, Rosabel, Miguel Cazorla & Jose Esteve Faubel (2023), 'Social robotics in music education: A systematic review', *Frontiers in Education* **8**.

Mueller, Florian Felix & Michael Rohs, eds. (2020), *Robotic Musicianship: Embodied Artificial Creativity and Mechatronic Musical Expression*, Springer.

Papert, Seymour (1980), *Mindstorms: children, computers, and powerful ideas*, Basic Books, Inc., USA.

Papert, Seymour M. (1994), *The Children's Machine: Rethinking School In The Age Of The Computer*, BasicBooks, New York.

Petrovič, Pavel & Fedir Agarshev (2024), 'Spike up prime interest in science and technology through constructionist games', *arXiv* .

Resnick, Mitchel, Eric Rosenbaum, Jay Silver & John Maloney (2017), *Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play*, MIT Press, Cambridge.

Santos, Adriano L., Marilia A. F. Marcondes, Daniela M. Filippo & Leonardo Bianchi (2015), Computação ubíqua para apoiar a educação musical: explorações com o makey makey, *em* 'Anais do XXIV Workshop sobre Informática na Escola (WIE 2015)', Sociedade Brasileira de Computação, Maceió, pp. 546–555.
URL: *https://sol.sbc.org.br/index.php/wie/article/view/16532*

Song, Heqiu, Konstantinos Tsiakas, Jaap Ham, Panos Markopoulos & Emilia I. Barakova (2024), "how would you score yourself?': The effect of self-assessment strategy through robots on children's motivation and performance in piano practice', *International Journal of Social Robotics* **16**(2), 327–340.
URL: *https://link.springer.com/article/10.1007/s12369-023-01080-3*

Weinberg, Gil & Scott Driscoll (2006), 'Toward robotic musicianship', *Computer Music Journal* **30**, 28–45.

Yakman, Georgette (2008), Steam education: An overview of creating a model of integrative education, *em* 'PATT-19 Conference: Research and Practice in Technology Education', Salt Lake City, UT, pp. 1–15.

Zelda Wiki (2024), 'Koji kondo'. Available online at `https://zelda.fandom.com/wiki/Koji_Kondo`.

Appendix A

Questionnaire 1: Students

- Age:
- School Year:

1. Have you had any contact with robotics before this activity?

   ( ) Yes

   ( ) No

2. Do you like music?

   ( ) Yes

   ( ) More or Less

   ( ) No

3. Did you find it easy or difficult to use EcoMusic?

   ( ) Very easy

   ( ) Easy

   ( ) More or Less

   ( ) Difficult

   ( ) Very difficult

4. Did you have fun while learning with EcoMusic?

   ( ) Yes

   ( ) More or Less

   ( ) No

5. Did EcoMusic help you better understand how music works (sounds, rhythms, notes, melodies, timbre, and silence)?

   ( ) Yes

   ( ) More or Less

   ( ) No

6. Did the operation of the instruments made from recyclable materials catch your attention?

   ( ) Yes

   ( ) More or Less

   ( ) No

7. On a scale from 1 (little) to 5 (a lot), how much did the robot help you understand what was taught?

   ( ) 1

   ( ) 2

   ( ) 3

   ( ) 4

   ( ) 5

8. Do you think using robotics and music together helps you learn in a different way?

   ( ) Yes

   ( ) More or Less

   ( ) No

9. What new things did you learn with EcoMusic?

10. What do you think could be improved?

Appendix B

Questionnaire 2: Teacher

1. Years of experience as an arts/music teacher:

   ( ) Less than 1 year

   ( ) 1–3 years

   ( ) 4–7 years

   ( ) More than 7 years

2. Grade level/segment you teach:

   ( ) Elementary I

   ( ) Elementary II

   ( ) High School

   ( ) Elementary I and II

   ( ) All

3. On a scale from 1 (low) to 5 (high), how would you evaluate the overall engagement of students in traditional music classes?

   ( ) 1

   ( ) 2

   ( ) 3

   ( ) 4

   ( ) 5

4. How would you rate students' interest in exploring sounds, rhythms, and instru-

ments?

( ) 1

( ) 2

( ) 3

( ) 4

( ) 5

5. How would you describe students' active participation (experimenting, asking questions, testing instruments)?

   ( ) 1

   ( ) 2

   ( ) 3

   ( ) 4

   ( ) 5

6. In your perception, to what extent do traditional music classes facilitate the understanding of basic musical concepts?

   ( ) 1

   ( ) 2

   ( ) 3

   ( ) 4

   ( ) 5

7. Main challenges observed in these classes (or with these students):

8. The level of student engagement while using EcoMusic was:

   ( ) 1

   ( ) 2

   ( ) 3

   ( ) 4

   ( ) 5

9. Did the use of robotics and recyclable materials increase student interest?

   ( ) 1

   ( ) 2

   ( ) 3

   ( ) 4

   ( ) 5

10. Did students demonstrate better understanding of musical elements (rhythm, intensity, timbre, etc.) with EcoMusic?

    ( ) 1

    ( ) 2

    ( ) 3

    ( ) 4

    ( ) 5

11. In your perception, did EcoMusic contribute to connecting music and sustainability?

    ( ) 1

    ( ) 2

    ( ) 3

    ( ) 4

    ( ) 5

12. Main difficulties/limitations observed when using EcoMusic:

13. Student participation in classes with EcoMusic compared to classes without EcoMusic:

    ( ) Less participative

    ( ) Equally participative

    ( ) More participative

14. Student interest in music in classes with EcoMusic:

( ) Lower interest

( ) Same level of interest

( ) Higher interest

15. Understanding of musical concepts in classes with EcoMusic:

    ( ) Worsened

    ( ) Unchanged

    ( ) Improved

16. Main pedagogical contributions of EcoMusic:
17. Aspects that should be improved:
18. Additional comments about the experience: