Establishing an Interdisciplinary Science and Art Program for Museums in Ecuador

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MUSEO PUMAPUNGO

Ministerio de Cultura y Patrimonio

República del Ecuador

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WPI

Establishing an Interdisciplinary Science and Art Program for Museums in Ecuador

An Interactive Qualifying Project Report Submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Project Site

Cuenca, Ecuador

Date Submitted

March 4, 2022

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Abstract

Ecuador has a lack of educational programs that connect science to art. Our sponsor, Museo Pumapungo wanted our team to establish a program that would help expose students to science concepts through connections to art. We achieved this though research, interviews, and observation. Our results assessed the resources at Museo Pumapungo, baseline physics knowledge of local students, and educational programs held at other museums. Our final deliverable is a workshop at the museum focusing on physics, sound, and music.

Acknowledgments

This project was not possible without the help, guidance, and support of the many people we have worked with. First, we must thank Museo Pumapungo for allowing us to take on this challenge. We want to extend a special thanks to our sponsors at Museo Pumapungo, Ximena Moscoso and Gabriela Arias. Thank you for providing us with an enjoyable experience and offering us the space for creativity throughout the process. Thank you also for your consistent efforts in finding us resources and contacts in Cuenca which were invaluable to completing this project.

We would also like to thank all the people we interviewed from both Museo Pumapungo and local schools. Without the vital information gathered from these individuals, we would not have been able to create our program.

Thanks must also be extended to all of the professors, teachers, and mentors who provided us with the base knowledge to complete this project. Thank you to Professor Courtney Kurlanska for teaching the methodology we used on this project as well as for providing guidance with our project proposal. Next, we would like to thank our on-site advisors Esther Boucher-Yip and Gary Pollice who provided helpful feedback throughout the project. We would also like to thank the WPI librarian Karen Coghlan who helped us with the background research necessary for our project.

Finally, one last thank you to Worcester Polytechnic Institute and Museo Pumapungo. Together, these institutions made our time in Cuenca, Ecuador possible.

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Executive Summary

Introduction

Ecuador has a lack of educational programs that create connections between sciences and the arts. Museo Pumapungo in Cuenca, Ecuador values teaching to the public and wanted our help with establishing this type of program for teaching physical sciences and art.

Background

Different techniques are used in general to teach the physical sciences that allow information to "stick" better for students. Interactive activities and activities outside of traditional classroom settings tend to be more valuable to students. We researched the current role of museums in science education and how museums recognize and highlight the connection between science and art. We explored the relationship between art and physics. We researched many different art-physics connections but for the project, we focused on the physics of sound and music. The research into these topics created a foundation for designing and establishing the program.

Methods

We focused on three main objectives. We started by identifying the resources of Museo Pumapungo that we could use to teach the physics of music. For this, we interviewed museum staff and completed formal and informal observations. The next objective was to determine the level of complexity for the program. This involved determining how much local students already know about the physics of sound. We interviewed local physics teachers about their academic plans and different topics the school covers. Our last objective was to determine elements of effective museum educational programs that we could incorporate into our workshop. We surveyed museums from around the world with established educational programs and looked for common elements. With our objectives established we collected all the necessary data to create the program.

Results

While completing the objectives, we collected the necessary data to build the program from the ground up. We established what our sponsors wanted for this program and what they have done in the past. They told us through multiple informal interviews that the program needed to be two hours or less. Students, especially younger students, have a difficult time maintaining focus for long periods of time, noting that as age decreases, so does the period of time they can maintain focus. The sponsor also suggested that no individual activity lasts more than 45 minutes for the same reason. Our sponsors highly encouraged us to consider using as much of the museum as possible. A key requirement they had was that the program should be designed for a group of approximately 20 students.

We used the museum's ethnographic exhibit to see what instruments were on display that we could base the program on or incorporate into the program. We completed two interviews with the curator of the archeological reserve. He showed us different artifacts the museum has and the sounds each makes. In addition, we scouted many locations at the museum to see areas we might use for the program. While we deemed many of the areas unsuitable for our project, because of location, space, travel time, or other issues, we also found many areas that were excellently suited for the project. We settled on five specific sites in and around the museum to use for our program.

During interviews with local educators, we determined what concepts are normally taught by physics teachers. We found out that sound and waves are a minor part of the curriculum. We also found the target age group for our program would likely be 13-17 year-olds. In addition, we learned that the teachers like having the opportunity to take the students outside of the classroom to reinforce topics. The teachers we interviewed expressed interest in our program and a desire to take their students on the program once it is up and running.

From other museums, we learned about elements of effective educational programs at museums as well as information to help improve students' experiences at museums. This information showed how interactive and informative each program was. We created a table to compile the data and analyze it for commonalities. We focused on specific aspects or characteristics of their educational programs that made them effective. The programs involving interactive components were the most informative and most memorable. So, we included interactive components in our program.

Conclusion

After all of our research, we came to the following conclusions. There are suitable locations at Museo Pumapungo that we used for the program. We located instruments and artifacts at the museum we used to teach physics. Students have a baseline level of physics knowledge but are not exposed to the physics of sound. Students in Cuenca begin learning physics at about the high school level, approximately age 13. Museums with field trip programs that were very interactive, relatively short (1-2 hours), and very visual were the most successful.

The final product we created was a 2-hour long workshop aimed at kids from middle to high school. The program took students all over Museo Pumapungo learning about the physics of sound and musical instruments through activities and demonstrations. Each section and activity was selected specifically so that they can relate to art.

In addition, each location was chosen such that the travel time is kept to a minimum so we can focus time on the activities and the students learning about how sound and music work. In addition, we focused on interactive elements and activities so the physics concepts would stay with the students longer. We were not able to test the program with actual students, so lots of data about fine-tuning the program was not gathered, however, we encourage Museo Pumapungo to test, refine, edit, and expand upon the program. Once the program is fully established, Museo Pumapungo will be able to take the template of our project and create new programs. Those other programs could be about any science topic like the physics of color, biology, or even astronomy.

Chapter 1: Introduction

Museums are institutions that combine local, regional, and national identity and culture with the main goal of informal education for both local and visiting people. As cultural institutions, museums provide escapism, social interaction, and informal or free choice education. By enabling learning outside a classroom setting, they can help students gain an appreciation and openness to various subjects while also helping them reinforce and retain knowledge.

Many students have difficulty engaging in physics. Physics is often presented in a complicated and non-personal way with many formulas, theories, and laws that can be difficult to relate to the real world. Especially at an introductory level, uninteresting presentations of physics likely deter students, especially those who identify as female or minorities. Because it is often a difficult subject to grasp in the classroom and its principles define how the world around us works, physics is a natural subject for experiential learning. A well-designed field trip can work with the in-class curriculum to provide hands-on experiences that reinforce concepts. Field trip programs present the information in a different way that may help increase students' understanding and promote engagement with the material (van der Veen, 2012).

Museo Pumapungo is an expansive cultural heritage site in the heart of Cuenca, Ecuador. It consists of architectural ruins, an ethnobotanical park, a theater, an aviary, and a museum that is home to both artistic and ethnographic pieces. The museum sought to take advantage of their extensive art and history collections and outdoor spaces to create an educational program that teaches physics through art and art through physics. With their indoor collections and outdoor architectural ruins and parkland, Pumapungo provides an excellent space for experiential learning that can complement a traditional school curriculum.

Our project goal was to develop a program that would use the museum's collections, artifacts, and spaces as laboratories for teaching physics. We focused on how museums develop educational programs and how to assess the effectiveness of the programs. Considering the museum and its collections, the feedback from the teachers, our research on creating educational programs for museums, and the different art-physics connections, we decided to focus on the physics of sound and the art of musical instruments. Our project goal was to present the physics of sound in a fun and hands-on way to help students better understand the concepts.

Chapter 2: Background

This chapter presents what we learned from literature about effectively teaching physical science, how to create effective museum education programs, and aspects in art that can be used to teach different physics phenomena.

2.1 Teaching the Physical Sciences

Physics is everywhere. As societies around the world become increasingly more knowledge-oriented, ample exposure and knowledge of science, technology, engineering, and mathematics (STEM) concepts have never been more valuable (Conceição et al., 1998). Competency in areas of science and technology is increasingly vital and required in jobs and disciplines of all types across all levels (Moomaw, 2013).

Studies suggest that long-term success within the STEM fields begins at the elementary levels (White, 2018). Further, an engaging and compelling STEM curriculum in early education can help spark lifelong interest within these disciplines. Promoting genuine interest and engagement in these areas lays the foundation for a love of science and increased confidence that can support further education (Moomaw, 2013). Core competencies taught and learned in early science and mathematics prepare one for future higher-education preparedness, professional success, and personal success (White, 2018).

2.1.1 Educational Techniques for Physical Sciences

With the myriad of educational techniques that can be used in STEM education, some are more effective than others. Techniques include traditional classroom instruction, hands-on experiential learning, and STEM-related experiments that occur outside of formal education, such as using fractions to measure ingredients while baking. The ability to pose interesting and thought-provoking questions, use real-world lessons, and engage students through interactive activities are all factors that lead to both higher retention of information and a heightened interest in scientific subjects (Srikoom et al., 2018).

More novel approaches to teaching such as experimental-based learning and science-related experiences provide students with better academic results and educational experiences over traditional classroom teaching. A science-oriented museum field trip is one example of experiential-based learning. Informal methods of learning open the door for an appreciation and openness to scientific topics, and can aid in the eventual mastery of technical information and scientific principles (White, 2018).

One of the most important societal contributions of museum exhibits is their ability to promote engagement for their visitors by presenting their contents with aspects of entertainment. Several educators who participated in a case study agreed that experiences such as science-oriented museum field trips effectively encompass experiential science learning. Further they agreed that experiential learning was an effective way to grasp specific concepts. While educators did not unanimously agree that field trips directly lead to students mastering technical information, they did agree that field trips can help reinforce science fundamentals. In turn, making them a valuable tool to help young students understand scientific principles and develop both critical thinking and observational skills (White, 2018).

2.2 The Current Role of Museums in Science Education

A museum's primary role in society is to educate (Hooper-Greenhill, 2007). To better understand the role that museums play in science education, we can look at a few ways existing museums teach science. The approach that science museums and museums of arts and history take to create a compelling science curriculum can differ significantly. Science museums often directly leverage their own scientific content, while museums of arts and history must find creative ways to educate through interdisciplinary programs. As both types of educational experiences serve a very similar role and contain significant overlap in approach, we included examples of both.

Modern science museums are places where visitors can learn science by experiencing science (Schiele, 2008). Historically, science museums existed as private collections of “artificial curiosities” and human-made works such as maps, primitive tools, and mechanisms (Semper, 1990). However, science museums have since evolved into public troves for sharing scientific knowledge. Many modern science exhibits strive to increase their effectiveness by being interactive, visually interesting, and fun. For instance, through these exhibits, museums now provide opportunities for students to be active participants in learning by manipulating real objects in a stimulating setting (Schiele, 2008). Science museums have evolved to not only be home to scientific and technologically significant artifacts but also be an experiential sandbox for all kinds of scientific concepts.

2.2.1 Museum of Science, Boston

The Museum of Science in Boston, see Figure 1, is among the world’s largest science centers and engages nearly five million visitors annually (Museum of Science B, Boston, n.d.). Their mission is to share scientific knowledge with everyone in a fun and accessible way. For instance, their “Science in the Park" exhibit explores physics topics such as harmonic motion, momentum, and mechanical advantage. Built to mimic a familiar park-like setting, it uses playground equipment such as swings and bicycle wheels to create an interactive learning ground. This connection to a playground encourages engagement, especially from younger visitors. The exhibit’s displays encourage visitors to draw individual conclusions, making them active learners. For example, visitors can race balls down varying tracks to see which is fastest to make conclusions on speed and

Figure 1.

Boston Museum of Science

Note. Ford, D. (2006). *Boston Museum of Science 1* [Photograph]. Flickr. https://www.flickr.com/photos/60597745@N00/312337838

acceleration. Their hands-on involvement facilitates their understanding of the material and retention of what they learned. Overall, the exhibits at the Museum of Science, in Boston Massachusetts are informative with science-related content while being engaging and fun, especially for younger visitors (Museum of Science A, Boston, n.d.).

2.2.2 Deutsches Museum

Another example of a science museum that uses fun and interactive exhibits to teach science is the Deutsches Museum in Munich, Germany, see Figure 2. The “Music Automata and Electronic Musical Instruments” exhibit explores musical automata, instruments that play music without a human playing them, and the production of sounds (Lein, n.d.). The exhibit encourages a fascination for the workings of the instruments, presenting visitors with functional examples of various historical mechanical and electronic instruments. The exhibit informs visitors through interactive components and features such as showing the inner workings of mechanical musical automata (Lein, n.d.). The exhibit uses the automata to get the visitor’s interest and then provides additional scientific content so that the visitor leaves with more scientific knowledge and a memorable experience that will reinforce the scientific concepts.

Figure 2.

Deutsches Museum

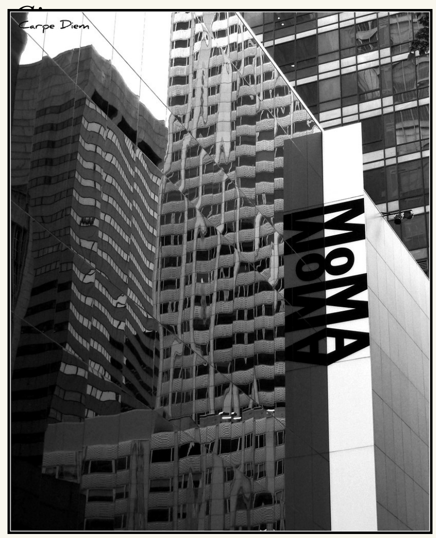
Note. Raab, H. (2018). *Deutsches Museum* [Photograph]. Flickr.https://www.flickr.com/photos/55276107@N00/43843663611

2.2.3 Museum of Modern Art

The Museum of Modern Art (MoMA) in New York City, see Figure 3, is an outstanding example of a traditional art museum that offers interdisciplinary educational programs and exhibits for both students and general visitors that combines art, history, and science. While science museums teach scientific knowledge utilizing scientific exhibits, MoMA offers educational programs that

Figure 3.

Museum of Modern Art, New York



Note. Fischer, T. (2009) *Exterior Reflection, MOMA, New York City* [Photograph]. Flickr. https://www.flickr.com/photos/tonythemisfit/4111205156

teach by creating and highlighting the connections to physical sciences that can be found in both history and art. Despite being a museum that focuses on modern art, MoMA offers official curricula that cross disciplines. “The Art of Science and Conservation” is an education program that covers topics related to optics and materials found within paintings. It provides students a sense of excitement through activities such as examining paintings under ultraviolet (UV) light themselves, rather than just providing UV photographs. The hands-on components help the students retain the information (The Museum of Modern Art, n.d.).

2.2.4 Worcester Art Museum

The Worcester Art Museum, located in Worcester, Massachusetts, see Figure 4, also offers science-oriented educational programs. The museum offers a “STEAM Tour” that incorporates art into STEM making it Science, Technology, Engineering, Art, and Math. The program takes students through a tour of the museum and focuses on the role of science and technology in the making and conservation of art. This curriculum also covers topics such as using art to understand the complex role our brains play in vision (Worcester Art Museum, n.d.).

Figure 4.

Worcester Art

Worcester, MA, USA [Photograph]. Panoramio. https://web.archive.org/web/20161015023532/http://www.panoramio.com/photo/38453405

2.3 Using Museums to Connect Science and Art

A collaborative series of temporary exhibits titled “Art and Science” created by the University of Otago and Otago Polytechnic Institute, both in North Dunedin, New Zealand, show how the general public can learn physics concepts through art. Two exhibits from the series, “Art and Light” and “Art and Space,” had a common goal of interesting people in science. They focused on using a method called scientific museology, which is used to connect science and art to the general public. Scientific museology is a way for people to see that physics and art are interconnected (Brook, 2017). For both exhibits, surveys found that no matter why people went to the exhibit, about 90% of them wanted to learn more about the science behind the art (Napper & Rock, 2015). Both exhibits taught different high level physics concepts at an introductory level to the general public. Thus, both exhibits achieved their goal of sparking interest in high-level concepts.

2.4 Relating Art to Physics

To an outside observer, art and physics may initially seem like two subjects in opposition to each other. Physics and other sciences are generally thought of as subjects that study the environment around us, how it functions, how it exists, and the rules that govern natural phenomena. Art is generally thought of as a very free subject that allows individuals to interpret the world around them in whatever way they wish to. It does not have to follow literally or understand the world concretely but is more subjective. However, both physics and art value and foster the ability of abstract thinking, and knowledge, as well as creativity (Godinovic, 2019). Physics and art are fundamentally intertwined and it is impossible to create art without also applying physics concepts. There are many different art forms that each lend themselves better to conveying different types of physics or science. Potential topics that connect art and physics are light and color, astronomy and storytelling, forces and sculpture, and thermodynamics and ceramics. An in-depth discussion of the physics of sound and music can be found in Appendix H.

Chapter 3: Methods

Prior to the global pandemic, Museo Pumapungo hosted student field trips. Typically, these on-site programs had a total duration of less than two hours and consisted of shorter sub activities. This was because students usually tend to have difficulty focusing for long periods. They encouraged us to make the program interactive to promote engagement and encouraged us to use all available spaces around the museum and its grounds. The museum can host and administer this project for a group of about 20 students. They also permitted us to incorporate supplemental materials to aid in demonstrating various physics concepts. With this, we decided to focus on the connection between the physics of sound and the art of music.

To help Museo Pumapungo create this educational program, we identified three primary objectives:

1. Identify the resources, including people, art, and historic artifacts within Museo Pumapungo that can help teach the physics of music
2. Determine the students' current level of physical science knowledge
3. Identify components of effective educational programs at other museums

With these objectives in mind along with our goal, to create an interdisciplinary educational program, the methods we used follow.

3.1 Identify Museo Pumapungo's Resources That Can Be Used to Teach the Physics of Music

The resources included the types of art on display, space for physics demonstrations, and people to run the program. We accomplished this through interviewing and observation. We conducted semi-structured interviews with museum staff, like Ximena Moscoso, and others who have worked with field trips or educational programs at the museum. See Appendix A for full interview questions, along with the Spanish translation in Appendix B. We chose interviews over a survey. Interviews allowed us to collect in-depth information and gave us the flexibility to let us guide the conversations in different directions as the interview progressed (Beebe, 2014). The interviews were approximately 20 minutes or until the discussion naturally came to an end.

We walked around the museum's ethnographic exhibit to learn what artifacts were on display. Through observation, we visited several of the museum's exhibits to identify any artifacts that might relate to physics, specifically sound. During that first walk-through, we looked for any art pieces that could be related to physics, brainstormed out loud, and took informal notes. We later conducted a more formal observation in the archeological reserve (the storage area for artifacts not currently on display) and filled out the table in Appendix C, to list pieces with a photograph and notes on how we may use it in our curriculum. The main goal of the observations was to relate specific artifacts or pieces to sound and music.

3.2 Determine the Students' Current Level of Physical Science Knowledge

To develop a program appropriate for the demographic, we needed to talk to local educators to know when students in Cuenca start learning about physics and what topics are covered.

Based on the level of physics education for local students and the age at which they start learning physics, we decided that our target age should be approximately 13-17 years olds. This is roughly the age of high school students. We thought it was critical to interview local educators that work with students in the target age range. We determined what physical science concepts students in that age range already know, what range they have in their baseline knowledge, what they learn in their school curriculum, and how schools work in Cuenca, Ecuador.

Since we only knew how school systems work in the United States, we needed to understand how schools work in Cuenca, Ecuador. To create a successful program, we needed to learn if teachers introduce physics concepts differently to students in the United States and Cuenca. We conducted semi-structured interviews with educators that teach the target age group. With the semi-structured interviews, we were able to prepare questions as well as follow the conversation to any other information the teachers thought was relevant. We constructed interview questions that focused on the school's science curriculum. We were only able to identify science and mathematics teachers for our interviews. In addition to the curriculum, we asked about what the students learned up to this point in their education. A full list of questions is in Appendix D and the Spanish translation in Appendix E. We used the results of the interview to help us understand what the students already knew and what they were expected to learn during the upcoming academic year.

3.3 Identify Components of Effective Educational Programs at Other Museum

To determine the best approach for creating an educational program at Museo Pumapungo, we assessed elements of successful science-related education programs and experiences offered by other museums around the world. We identified 15 well-established and well-known museums that offer such experiences. A full list of the museums we used as well as why they were selected can be found in Appendix F.

We identified factors such as how informative, interesting, engaging, creative, and interactive an exhibit or program is in creating an effective educational program. We created a table (Appendix G) adapted from MacDonald, (2015) and Kabassi et al. (2019) to evaluate each museum experience.

Chapter 4: Findings

We found that the data we collected would later help us with creating the workshop. Although we were not able to physically test the program with students, we created a prototype of how the program could be laid out. This prototype was created to be filled with any workshop with a connection between science and art.

4.1 Introduction

In preparation for creating a program to help students learn about the connections between art and sound, we first had to complete fieldwork and interviews. Our key findings from our research were:

- There are suitable locations at Museo Pumapungo that we can use for the program.
- We located instruments and artifacts at the museum we can use to teach physics.
- Students have a baseline level of physics knowledge but are not exposed to the physics of sound.
- Students in Cuenca begin learning physics at about the high school level, approximately age 13.
- Museums with field trip programs that were very interactive, relatively short (1-2 hours), and very visual were the most successful.

4.2 What We Learned from Identifying the Resources and Needs of Museo Pumapungo

To create an effective program for students we scouted Museo Pumapungo for their resources, and to understand their needs and wants. This involved looking at different objects for inspiration, visiting locations where we would be able to have activities, and looking at art and artifacts that they would be able to use. We found one artifact that we can use during the tour and 5 locations at the museum we can use. We walked through the ethnographic exhibit and spotted multiple instruments. Using the historical instruments helped us create activities for the workshop. For an in-depth understanding of how each type of instrument works, see Appendix I and the Spanish translation in Appendix J. In addition, we had multiple conversations with our sponsors and museum staff. In an informal interview with a staff member, we learned about an artifact, the whistle bottle, and played the replica to understand the physics behind the instrument. More information is located in Appendix I.

4.2.1 Results of Formal Observations from the Archeological Reserve

We conducted formal observations with the Curator of the Archeological Reserve, Marcello Guiracoha, of sonic artifacts to gain more insight into historic Ecuadorian instruments and sound-producing objects. The reserve is home to 10,057 artifacts mainly from the Pre-Columbian cultures of the coastal regions of Ecuador.

The first artifacts that we looked at were the ocarinas. Ocarinas are instruments in the flute family, similar to a whistle. The ocarinas in the

Figure 5.
Ocarina

Note. This is one of the ocarinas from the archeological reserve.

reserve were all ceramic female figures with five holes, depicted in Figure 5. The ocarinas are from the Bahia culture in the central coastal region of Ecuador, dating back to between 500 BCE and 800 CE. Even though we were not able to hear the real artifacts make sound, the museum staff granted our group access to the Google Drive folder with sounds each artifact made. The ocarinas themselves sound like a modern-day train whistle.

The other artifacts we looked at were mostly whistle bottles. We saw an original whistle bottle from the Jama-Coaque people of the coastal region of Ecuador from between 300 BCE and 800 CE. We also saw a replica that we were allowed to touch, and the original can be seen in Figure 6. We learned that we would be able to use the replica for the program itself, where only the guide was allowed to hold and play it. When comparing the two side by side, we immediately noticed differences. The

Figure 6.
Original Whistle Bottle

Note. Produces sound by filling the chamber with water then tilting the bottle

original whistle bottle's basins are larger and the middle section smaller, the replica was made to sound as similar as possible to the original, not look exactly like the original. We saw many other whistle bottles that all produce a similar sound but have different exteriors and differently shaped basins, changing the pitch of the sound. All of the different shaped whistle bottles date sometime between 1500 BCE and 800 CE.

Other artifacts we viewed varied much more. One was a bell made of a giant piece of rock with the middle carved out. We were able to hear this bell being played, and it produced a long and loud tone. Another type of object we saw was flutes made of bone. They mentioned that different cultures used human bones or animal bones.With the aforementioned Google Drive, we listened to them being played. The flutes, one pictured in Figure 7, were fractured, which changed the sound. The holes down the bone allowed musicians to play different notes similar to a modern-day recorder. The ones we saw were from the Jama-Coaque people and they were very difficult to play. When sound was produced, the sound was airy like a woodwind instrument with a range of pitches. Each flute was unique since they could produce different pitches.

Figure 7.
Bone Flute

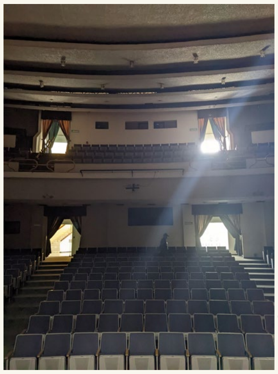
Note. This is one of the many flutes the museum has in the reserve

4.2.2 Results of Location Scouting of Museum Grounds

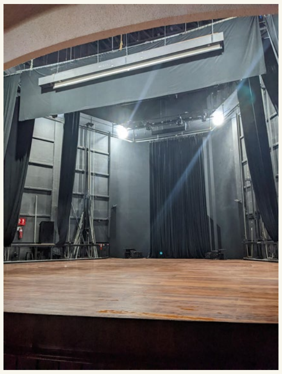
We scouted locations that we could use for the workshop. At each location, we listened to the acoustics and brainstormed feasible activities. We focused on reverberation, how sound moves through a space. We also looked at each space, the equipment in the area, and the ambient noise of the space to determine which activities or demonstrations could realistically be done there. While we looked at many different locations, some we decided not to use for the program for various reasons including size, acoustics, or the presence/absence of artifacts. The spaces we did not use will not be discussed here.

We visited Teatro Pumapungo, pictured in Figure 8. Both inside and outside the theater itself have the potential to house several different activities. In the building, the acoustics differ depending on where you stand (onstage, in the audience, backstage, in the pit, etc.). Inside of the theater, the acoustics have little to no reverberation.

Figure 8.
Teatro Pumapungo



(A)



(B)

Note. View of the stage (A) and the audience (B) at Teatro Pumapungo.

The theater was designed in such a way that a signer does not need a microphone for the entire audience to hear them. The area itself is very large and open, with lots of space for students to go on stage for activities. In addition, one of our sponsors, Ximena, told us that a beatboxer, opera singer, or musicians from the symphony could be made available for the program.

There are many spaces in the museum that we also utilized for the program. The auditorium, Figure 9, was an excellent space with minimal echo, space for up to 100 kids, a projector and screen, and microphones. We could use several of these resources to demonstrate various aspects of sound. The team decided that the auditorium would be a great place for the program to start, as it could be used for demonstrations and explanations.

Pumapungo is not just a museum, but also an archaeological park. Behind the museum is a

Figure 9.

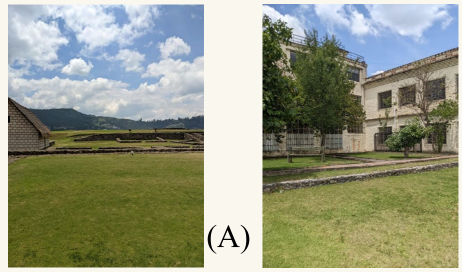
Auditorium

Note. This room is an auditorium and is like a classroom and has a projector, podium, small stage, and room for up to 100 students.

large open area with ruins, gardens, and an aviary. Outside, you have to walk past Colegio Borja before getting to an open area with several trees that we decided to use for a physics demonstration, see Figure 10. It takes a while to walk out to the archeological park and gardens, so utilizing this

Figure 10.

Outside Pumapungo by the Ruins



(A) (B)

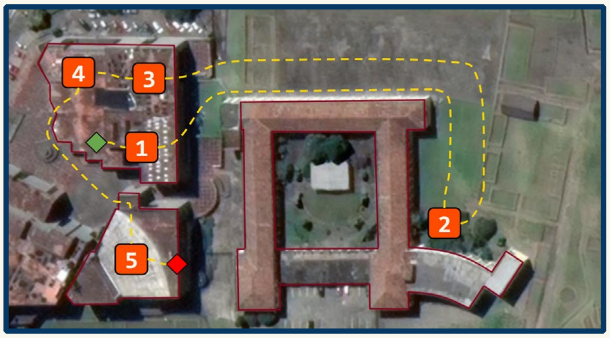
Note. The image on the left is facing away from Colegio Borja (A) while the image on the right is facing Colegio Borja (B).

space for a demonstration or discussion would be good.

After surveying the locations at Museo Pumapungo, we started to create a picture of what the workshop would look like for the students by mapping out the locations, see Figure 11. In addition, we used the locations to brainstorm more ideas for activities. This allowed us to start the process of outlining the movement of the program.

Figure 11.

Program Route



Note. The route students will take on our program in order.

4.3 What We Learned from the Educators

We interviewed two local educators for this project. Both teach high school physics at private schools in or around Cuenca. The first local educator we interviewed taught students ages 15-16. In their physics classes, students mostly learn about basic movement (straight line, vertical, rotation, parabolic), and Newtonian physics. Many of the students also take calculus at the same time. The second local educator we interviewed taught students ages 15-17. In their physics classes, the students also primarily learn about basic movement (straight line, parabolic, circular), energy and energy transfer, movement, and gravity. The older students also get exposed to the basics of harmonic movement and optics.

The way physics is introduced to students in Cuenca seems very similar to the way students in the United States are introduced to physics. They start with simple straight-line movement and basic Newtonian concepts. While students in Cuenca learn a decent amount of physics in school, the physics of sound is not emphasized. The students have to study for their end-of-year standard exams, so topics covered on those exams are more emphasized in the classroom. There is not much acoustics on those exams, so the physics of sound is left to the wayside. Curriculums may cover basic waves, the doppler effect, transmission, and frequency, but only briefly. The teachers we interviewed were very interested in our program and expressed interest in taking their students to Pumapungo to experience it.

4.4 What We Learned Researching Other Museums

Almost all of our research on other museum programs had to be done online. Ideally, we would visit these museums and experience their educational programs firsthand. However, due to the feasibility of visiting museums around the globe and the lack of such museums in Ecuador, research had to be done virtually. Reading descriptions virtually of these programs made answering questions like, "is it interactive?" "Is it engaging?" and "is it overall memorable?" very difficult to answer. Despite these difficulties, we found descriptions to answer our questions. A table with some of our compiled data can be seen in Appendix K and a shortened preview of the compiled data is also shown below in Table 1.

Table 1

Online Museum Research Data

Museum	Rating	Is it Interactive? How?
Museum of Science, Boston USA	**5**	Yes, interactive experiments and equipment
Providence Children's Museum, Providence USA	**4.5**	Yes, interactive pieces/exhibits
Getty Center, Los Angeles USA	**4**	Yes, thought-provoking questions
Cuerpos Humanos Reales, traveling exhibit, seen in Cuenca, Ecuador	**4**	No
Worcester Art Museum, Worcester USA	**3**	Yes, discussion
The British Museum, London England	**2**	Yes, questions and group activities
Korea National Museum of Modern and Contemporary Art, Multiple Locations, South Korea	**1**	No

Note. A few columns of data we collected from researching other museum educational programs that we thought contained pertinent information. The rating scale is from 5-1 with 5 meaning that we really liked the program and 1 meaning that we really did not like the program.

Most of the museums we researched have well-established educational programs and offer a variety of programs with different concentrations and aimed at different age groups. For example, the Maryland Science Center in Baltimore Maryland offers at least twelve different "enrichment experiences" (their term for educational programs) for schools. Each experience is designed for kids in specific grades and targets different scientific topics like circuits, DNA, or statistics. The Brooklyn Museum in Brooklyn, New York, offers at least six different topics for field trips to focus on for students in various grades including "Art and Activism," "Belief Systems and Community," and "Art Stories." For Museo Pumapungo, we created a framework for field trips that the museum can take and expand to add more programs with a variety of different themes long after we leave Ecuador.

Some common aspects among the museum educational programs we researched were that they had a 1 to 2 hour tour of the museum either guided by museum staff or the teacher. Most of the programs we liked the most, indicated by a 4 or 5 rating, also included interactive elements like open-ended or guiding questions for students, conversations or discussion, small science experiments, demonstrations, art projects, writing exercises, scavenger hunts, or interactive exhibits. Additionally, some programs incorporated free time for students to explore the museum at their own pace. Several of the museums also included post-field trip questions or surveys for students to fill out. This helped students retain information from the field trip and also gave the museums ideas of what the kids liked and disliked about the tours. It would have been best if we could interview students to see how they like these different portions of museum programs, but we are not able to do so. Instead, from our own experiences as students on field trips, we will incorporate the aspects we found most engaging.

At many of the museums, the cost of admission was free for all participating students, teachers, and chaperones as long as they were local. Others had small fees for students from out of state or general fees for experiences other than entrance to the exhibits. For example, taking a group of students to the Maryland Science Center is free for Maryland students and teachers, but adding one of the "enrichment experiences" costs an additional fee. Since admission to Museo Pumapungo is free, we agreed that our program should also be free. Since the program was free, we could not spend lots of money on supplies.

From all of the research conducted on other museums, it seems like a very important aspect of the program should be the connection between the museums and the schools. The museums that emphasize the importance of outside-the-classroom learning seemed to have the most interesting sounding programs as well as programs that paralleled what students would learn during their school year. These programs should complement the current classroom education and give educators the freedom to design or choose aspects of the program they see as most relevant.

Chapter 5: Conclusions and Recommendations

In this chapter, we present our key findings, a summary of the project deliverables, several recommendations for Museo Pumapungo, project limitations, and possible directions our project could take in the future. Through interviews and observations, we gained a deeper understanding of the core need that Museo Pumapungo wanted to address. Due to time constraints, the team focused on creating a prototype program. Through our research, we decided that our final deliverable should be a detailed outline of an example educational field trip to Museo Pumapungo.

5.1 Key Findings

- There are suitable locations at Museo Pumapungo that could be used for an educational program.
- There are instruments and artifacts at the museum that could be used to demonstrate and teach physics concepts.
- Local students in Cuenca have a baseline level of physics knowledge but are not widely exposed to the physics of sound.
- Local students begin learning physics concepts around the beginning of high school, approximately age 13.
- The most effective existing educational museum programs were very interactive, relatively short (1-2 hours), and highly visual.

5.2 Our Deliverable

By visiting the museum and walking through our program, we found the most accurate times for each section of the program. From this, we created a detailed schedule for the student's time at Museo Pumapungo along with detailed explanations of the physics concepts and activities. We decided that our deliverable would be more effective if it was presented as a detailed schedule since it would be straightforward for anyone to follow.

The program begins in the auditorium where students receive an introduction to sound, and musical instruments at the museum. This includes a more general description of the way sound works with a focus on sonic instruments. This part of the program is crucial because the guide will gauge the students' baseline knowledge of sound prior to arriving at the museum. There is also a demonstration with the replica of the whistle bottle to draw in the attention of the students. The program had to start with an engaging activity to draw in the students' attention.

After the introduction in the auditorium, the guide leads the students outside of the museum to the archeological park to demonstrate waves to the students using a rope. We chose this activity because it allows for students to clearly see what waves are and their different behaviors, being an enlarged version of a string instrument. Our sponsors told us that from their experience, students have the best attention at the beginning of the program, so we wanted to get the technical concepts addressed early. From previous research, we learned that when a program is interactive, students learn more. Each part of this activity allows the students to learn different concepts that will be applied later.

Next, the students return inside for a 10-minute break. Where the students will be allowed to look around planta baja. With their knowledge from the beginning of the day the student can recognize different instruments in the area like whistle bottles or ocarinas. Our sponsors wanted us to include this break so the day can be broken up and the students have time to use the bathroom, grab a drink, or take a break from the intense material they learned.

The students then go into Sala Ludica to create their own instruments. This activity was chosen because the students can apply the concepts they learned earlier and make their own versions of historical instruments. It is also interactive, tactile, and creative for the students. The students will tie in the knowledge learned throughout the previous hour in a practical environment. This location was specifically chosen because it is on the ground floor, it is a private area, and it has table space for crafting. These factors are important because staying on the ground floor minimizes travel time. It is also a private area, so the students would not be disrupting the guests visiting the museum.

The final part of the workshop is in the theater. Students will be allowed to test their instruments (COVID safely) in the area just outside the theater so they can hear them. The final activity involves students using their ears to determine which pitches are higher and which are lower. Each student will be given a piece of PVC pipe, similar to a boomwhacker, that plays a unique note. The students will then be tasked with putting themselves in order from lowest pitch to highest pitch. The students will then explain why some "boomwhackers" produce a lower pitch and others produce a higher pitch. This activity was chosen because it incorporates aspects from what they learned throughout the day. After they are done with that activity, the students will create their own song using the instruments they created, the boomwhackers, and their voices. We believe that this is an appropriate wrap-up activity and it is a fun way to end the program instead of ending with a quiz.

Throughout the day, we introduced concepts that arise later on when completing the other two activities. Since the concepts are only an introduction. We have also created an in-depth explanation for all of the concepts. The full in-depth explanations can be found in Appendix I, and the Spanish translation can be found in Appendix J. We needed to create this for the guide so that they can answer questions that are beyond the scope of the workshop.

5.3 Recommendations to Museo Pumapungo

Our overall recommendations to Museo Pumapungo are:

- Test the program with several groups of students, provide them with pre and post-workshop surveys to determine what they learned from the program as well as how they liked the program.
  - The individual activities could even be tested to determine exactly how long they take and whether or not they are engaging for students
- Keep the scripts in the deliverable as living documents; they can be added to or changed as the program is tested to make concepts clearer.
- Use the program as a template, so that once it is off the ground and working, it can be adapted to suit other physics concepts like light or forces, or even topics outside of physics like biology or chemistry.
- Add labels with descriptions of the artifacts to the exhibits to help people just walking through the exhibit understand the pieces better and the physics behind them.

We strongly encourage Museo Pumapungo to extend, modify, and test the program so they can fine-tune it to their liking. We did not have time to allow students to test our program, but we strongly recommend having students who attend the program give feedback so that the museum can improve the program. After we leave, create some sort of "exit survey" for students including questions like "rate your overall experience," "what did you particularly like," "what did you particularly dislike," or "what could we have done better." Use the feedback from the exit surveys to improve the program. Once the program is up and running smoothly, expand the program to include workshops based on other physics concepts like light so that educators could choose the type of field trip for their students

Museums are a great tool for education, but we found that without a tour guide a visitor can miss out on a great deal of learning. Currently, very few of the artifacts have associated labels or informational diagrams so it is difficult for self guided tours or the general public to get a deeper understanding of pieces in the museum. Having information such as what the artifact is, where it was found, when it was found, or applicable physics concepts would allow both students and the general public to have a more self-guided experience within the museum. This would allow anyone who enters the museum to understand the physics of pieces, rather than just the students who attend our workshop. These labels could either be only in Spanish or also have an English translation for the ex-pats/tourists who visit the museum.

5.4 Limitations of Our Project

The biggest limitation of our project was that we were not able to test the final deliverable with students. We were not able to make adjustments to the program and observe aspects of the program like if the information is too advanced or too basic or where we would lose the student's attention. We have only created a prototype of the program. If we had been able to view the program or even just the activities in action with students, we would be able to improve our program. We were not able to see if there were activities that the students were not engaged in or did not particularly like. This knowledge would have been crucial to creating the program.

Another limitation of the project was that we were only able to interview two local teachers. Both of the two educators teach students about 15-17 years old and at private schools. It would have been nice to get input from more educators at different types of schools who teach younger students. We do not know much about the baseline science knowledge of younger students, but the program was still designed in a way that young students would be able to learn new concepts.

5.5 The Future of Our Project

The combination of physics and art provided by our program will help future students of Cuenca engage with and be excited by physics. No program like this, combining science with art and history at social science museums, exists in Ecuador. Hopefully, the framework we created will be successful enough for museums around the country to apply. Our program focuses on the connection between sound, music, physics, and history through the pieces at the museum, but using the framework we created, the museum could create other programs based on topics like light and color, astronomy, forces, or ceramics.

Museo Pumapungo is a living place and while there are many permanent exhibits, there are also temporary exhibits. We did not want to depend on the structure of the museum exhibits, but rather only incorporate certain elements with teaching and activities. This way we hope the curriculum will have longevity and adaptability within the museum.

Our project is still quite young and has lots of growing to do. This project has the potential to be expanded upon by other IQP teams from WPI as it continues to grow. Future IQP teams could observe our program, gauge its effectiveness, and work to improve or adapt the program. Future IQP teams could also expand upon science education at the museum by introducing additional science topics to stand alongside our workshop educational program at Museo Pumapungo.

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Appendices

Appendix A: Museo Pumapungo Interview

Interview Preamble

My name is (group member name), and I am from a group of students from Worcester Polytechnic Institutes in the US working with Museo Pumapungo. We are working on a project to help them create an educational program that teaches physics through art. The purpose of this interview is to learn more about the resources the museum has. If you are willing to do so, would you please answer some of our questions?

No - Have a good day

Yes - Before starting, please know that this interview is entirely voluntary, and you may stop or refuse to answer questions at any time. This interview is completely anonymous, and you will not be identified in any way. We will be taking notes if that is okay with you. If you would like to contact us, please email us at gr-pumapungo@wpi.edu or our advisors Gary Pollice gpollice@wpi.edu and Esther Boucher-Yip, efboucher@wpi.edu.

Semi-Structured Interview Guiding Questions- Museum Staff

1. Could you please explain what you do at the museum?
2. Has the museum ever hosted field trips before? If so, please describe them?
    a. What time did the students arrive at the museum?
    b. How many students were there?
    c. What age range were the students?
    d. What did the students do while they were here? Was it a tour of the museum? Did they also go out to see the ruins, gardens, or aviary?
    e. Were there any special activities planned for the students?
    f. How long did the program take?
    g. Did the students bring their lunches (if the program lasted all day)?
3. Please describe any educational programs the museum has done before
    a. Specifically, have there been any programs focused on STEM topics?
4. Is there a space where the students could gather to listen to someone speak or do an activity?
5. Can the museum purchase objects that could help explain physics concepts like a slinky or rope?
6. Who would be the person in charge of leading the students through the program we make?
    a. Do they have any existing physics knowledge to answer questions the students may ask?

7. Do you have any suggestions of other people we could talk to who could give us additional information?

Appendix B: Museo Pumapungo Interview (Spanish Translation)

Preámbulo de la Entrevista

Me llamo (nombre), y soy de un grupo de estudiantes de WPI en los Estados Unidos que trabajan con el Museo Pumapungo. Estamos trabajando en un proyecto para ayudar al museo a crear un programa educativo que enseñe física a través del arte. Si está dispuesto a hacerlo, ¿podría responder algunas de nuestras preguntas?

No - Que tenga un buen día

Sí- Antes de empezar, tenga en cuenta que esta entrevista es totalmente voluntaria y puede detenerse o negarse a responder preguntas en cualquier momento. Esta entrevista es completamente anónima y usted no será identificado de ninguna manera. Tomaremos notas si le parece bien. Si desea contactarnos, envíenos un correo electrónico a gr-pumapungo@wpi.edu o a nuestros asesores Gary Pollice gpollice@wpi.edu y Esther Boucher-Yip, efboucher@wpi.edu.

Nombre

1. ¿Podría explicar lo que hace en el museo?
2. ¿Alguna vez el museo ha organizado excursiones antes?
    a. ¿A qué hor llegaron los estudiantes?
    b. ¿Cuántos estudiantes?
    c. ¿Qué rango de edad tenían los estudiantes?
    d. ¿Qué hicieron? ¿Fue un recorrido por el museo? ¿Visitaba las ruinas, el jardín, o la pajarera?
    e. ¿Hubo alguna actividad planificada?
    f. ¿Cuánto se tardó?
    g. ¿Trajeron sus propios almuerzos? si el programa fue por día total.
3. Por favor ¿puede describir cualquier otro programa educativo que el museo haya hecho antes?
    a. Específicamente si había programas de STEM
4. ¿Hay un espacio para los estudiantes escuchar a una persona hablar o hacer una actividad?
5. ¿Puede el museo comprar objetos que ayudarían a explicar conceptos de física, como un slinky o una soga?
6. ¿Quién se encargaría de liderar el programa?
    a. ¿Tiene conocimientos existentes de física para responder preguntas?
7. ¿Tiene otras sugerencias de personas que hablarían y darían más información a nosotros?

Appendix C: Museum Observation Template

Image of piece	Name of piece	Specific connection to physics/what concept does this explain?

Appendix D: Educator Interviews

Interview Preamble

My name is (group member name), and I am from a group of students from Worcester Polytechnic Institutes in the US working with Museo Pumapungo. We are working on a project to help them create an educational program that teaches physics through art. The purpose of this interview is to learn more about the school day. If you are willing to do so, would you please answer some of our questions?

No - Have a good day

Yes - Before starting, please know that this interview is entirely voluntary, and you may stop or refuse to answer questions at any time. This interview is completely anonymous, and you will not be identified in any way. We will be taking notes if that is okay with you. If you would like to contact us, please email us at gr-pumapungo@wpi.edu or our advisors Gary Pollice gpollice@wpi.edu and Esther Boucher-Yip, efboucher@wpi.edu.

Semi-Structured Interview Guiding Questions- Educators

Part A: General questions for the Educator

1. What is the name of the school where you teach?
2. Is it a private or public school?
3. What ages of students do you typically teach?
4. How many students do you have in one class?
5. What subjects do you teach or specialize in (or do you teach everything)?
6. Do you or have you (personally) taken the students on field trips?
7. Are you currently comfortable taking students on field trips?
8. Do you think the school or parents would allow the students to go on field trips?

Part B: Determining the Academic Level

1. What will the students be learning this year?
2. What have students already learned from previous years?
3. Do you think the following topics would be appropriate for the students to learn?
    a. How musical instruments work
    b. Soundwaves, vibrations, frequencies
4. If it's possible, could you send us a copy of your syllabus?

Appendix E: Educator Interviews (Spanish Translation)

Preámbulo de la Entrevista

Me llamo (nombre), y soy de un grupo de estudiantes de WPI en los Estados Unidos que trabajan con el Museo Pumapungo. Estamos trabajando en un proyecto para ayudar al museo a crear un programa educativo que enseñe física a través del arte. Si está dispuesto a hacerlo, ¿podría responder algunas de nuestras preguntas?

No - Que tenga un buen día

Sí- Antes de empezar, tenga en cuenta que esta entrevista es totalmente voluntaria y puede detenerse o negarse a responder preguntas en cualquier momento. Esta entrevista es completamente anónima y usted no será identificado de ninguna manera. Tomaremos notas si le parece bien. Si desea contactarnos, envíenos un correo electrónico a gr-pumapungo@wpi.edu o a nuestros asesores Gary Pollice gpollice@wpi.edu y Esther Boucher-Yip, efboucher@wpi.edu.

Nombre

Parte A: Preguntas generales

1. ¿Cómo se llama la escuela donde enseña? y ¿dónde está la escuela?
2. ¿Es una escuela privada o pública?
3. ¿Qué edades de estudiantes suele enseñar?
4. ¿Cuántos estudiantes tiene en una clase?
5. ¿En qué materias enseña o te especializa?
6. ¿Usted o ha llevado (personalmente) a los estudiantes a excursiones?
7. ¿Se siente cómodo actualmente llevando a los estudiantes a excursiones?
8. ¿Cree que la escuela o los padres permitirían que los estudiantes hicieran excursiones?

Parte B: Este parte es para resolver el nivel académico

1. ¿Qué aprenderán en general los estudiantes este año?
2. ¿Qué han aprendido los estudiantes de años anteriores?
3. ¿Crees que los siguientes temas serían apropiados para que los estudiantes los aprendan?
    a. Cómo funcionan los instrumentos musicales
    b. Ondas sonoras, vibraciones, frecuencias.
4. Si possible, ¿nos podría enviar su plano de estudio?

Appendix F: 15 Museums Researched and Why

Museum, Location	Why it was selected
Museum of Science, Boston USA	It is one of the largest science museums in the world
Maryland Science Center, Baltimore USA	The large variety of programs available
National Museum of Play, Rochester USA	Have never seen play as the subject of a museum, it is very interactive, has multiple different programs
Providence Children's Museum, Providence USA	Memories from childhood. New England Science museum for children with an established education program.
Getty Center, Los Angeles USA	An impassioned article about the importance of outside the classroom learning
Cuerpos Humanos Reales, traveling exhibit seen in Cuenca Ecuador	A science exhibit in the projects local region
Deutsches Museum, Munich Germany	Covers a vast array of unconventional scientific exhibits
Rockwell Museum, Corning USA	History of science museum
Smithsonian Museum of Natural History, Washington D.C. USA	Memories of field trips as a kid as well as it is one of the most well-known museums
The Metropolitan Museum of Art, New York City USA	Offers interdisciplinary curriculums in various disciplines
Worcester Art Museum, Worcester USA	Offers interdisciplinary science education programs despite being an art museum
Brooklyn Museum, New York City USA	A good website in addition to being a well-known museum
Field Museum, Chicago USA	Well known children's science museum in Chicago USA
The British Museum, London England	Interest in museums outside the US and it has a well-established educational program
Korea National Museum of Modern and Contemporary Art, Seoul South Korea	International museum with an education program, that focuses on art, wanted to see if it incorporated science at all.

Note. Various google search terms were used to find each museum and each team member also used different methods.

Appendix G: Evaluating Online Museum Educational Programs Table

Criteria for Evaluating Scientific Education at Museums

Name of museum	
City, Country	
Is this specifically a Science Museum/Exhibit?	
Is there an Established Educational Program?	
Brief description	
Initial impression	
Is it engaging? How?	
Is it fun? How?	
Is it creative? How?	
Is it interactive? How?	
Is it overall interesting?	
Does it tell a story?	
Is it overall memorable?	
How informative is it?	
What is the level of complexity of the content?	
Could it be valuable to students?	

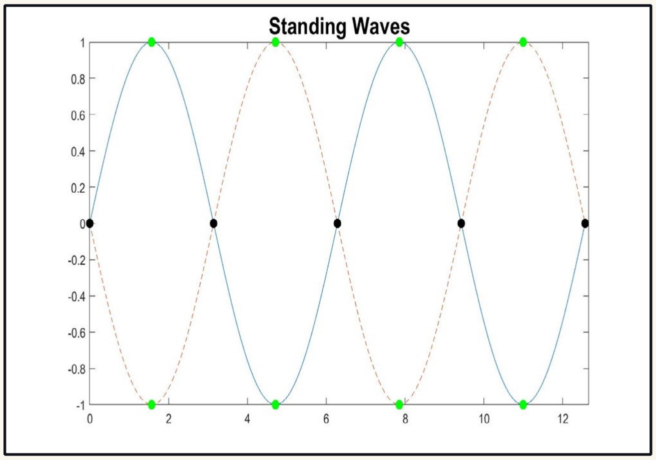
Other unique components?	
Pricing	
Other thoughts?	
Rating 1, 2, 3, 4, 5	

Appendix H: Sound Physics Connection

Part A: Sound: Waves

Music is not just a form of art. It is the everyday compilation of many complex physics phenomena and concepts. Sound is vibrations that travel through air or another medium and can be heard when they reach the ear. These vibrations move as waves. There are two main types of waves: traveling waves, and standing waves. Traveling waves are waves that are not bound to their medium. They move across the medium in one direction like an ocean wave. A standing wave is limited to a particular medium, like the string of a guitar. The standing wave moves back and forth through the medium as shown in Figure 12. (Young et al., 2020). The sound produced by string and wind instruments comes from standing waves. A standing wave is the sum of many simultaneous waves, where the sum looks like the wave in Figure 12

Figure 12.



Note. For a standing wave in a string instrument, the x-axis is position, and the y-axis

Standing waves have two noteworthy points, the nodes, and antinodes. Nodes are positions that appear stationary. The nodes are represented by the black dots in Figure 12. The antinodes are the peaks and valleys of the waves, represented in Figure 12 by the green dots (Young et al., 2020). For instruments, it is important to note if the ends of the media the wave travels through are fixed or open. Guitar strings, for example, have two fixed ends that are nodes, like in Figure 12 (Maor, 2020). Wind instruments, like clarinets, have one fixed end and one open end. The open end is an antinode. The sound and the mathematics that helps determine notes, harmonies, and octaves differ if the instrument has two fixed ends, two open ends, or one fixed end and one open end.

Part B: Sound of Stringed Instruments

When a musician plucks the string on a guitar, it produces many waves of many different lengths. The frequency is defined by the distance between peaks of the sound wave. The fundamental frequency is defined as the lowest frequency and is the one used to describe the group of frequencies produced when the string moves (Maor, 2020). The fundamental frequency has the fewest nodes. Since both ends of the strings on stringed instruments have fixed points, the fundamental frequency has two nodes. For strings, the fundamental frequency depends on its tension, length, and mass (Benson, 2013). The fundamental frequency essentially corresponds to the note or pitch of the string.

Strings need to be tuned so their fundamental frequency corresponds to the desired note. A plucked string vibrates at its fundamental frequency and at every integer multiple of that frequency. Adding each integer multiple of frequency adds a node to the standing wave (Young et al., 2020). Striking a string harder does not change the frequency or pitch. Rather it changes the amplitude of the wave, making the sound louder. To change the pitch of a stringed instrument like a guitar, a musician can make a string shorter by pressing it down at a fret. This increases the fundamental frequency, making the note higher (Young et al., 2020).

Part C: Wind Instruments

Wind instruments work slightly differently than stringed instruments. Wind instruments have either a wedge or reed that interacts with air to produce the sound. Air flows over a wedge and creates turbulence in wind instruments like flutes. Air flowing over a reed in a wind instrument like a clarinet vibrates the reed at all frequencies (Benson, 2013). For all wind instruments, the instrument's entire body is a resonance chamber for the vibrations. Opening and closing holes at various places along the body of the instrument creates standing waves with specific fundamental frequencies and nodes (Benson, 2013). Although all frequencies exist in the instrument's body, a musician can control the specific standing wave and resulting musical note by changing the length of the cavity or opening valves. Instruments like an organ or pan flute use many tubes of different lengths, each with a unique fundamental frequency and note (Young et al., 2020). To play different notes, the air flows across different tubes of different lengths. Because each tube's length and diameter are specially designed to release specific frequencies, unique notes occur.

Appendix I: In-Depth of Physics Concepts Covered in the Program

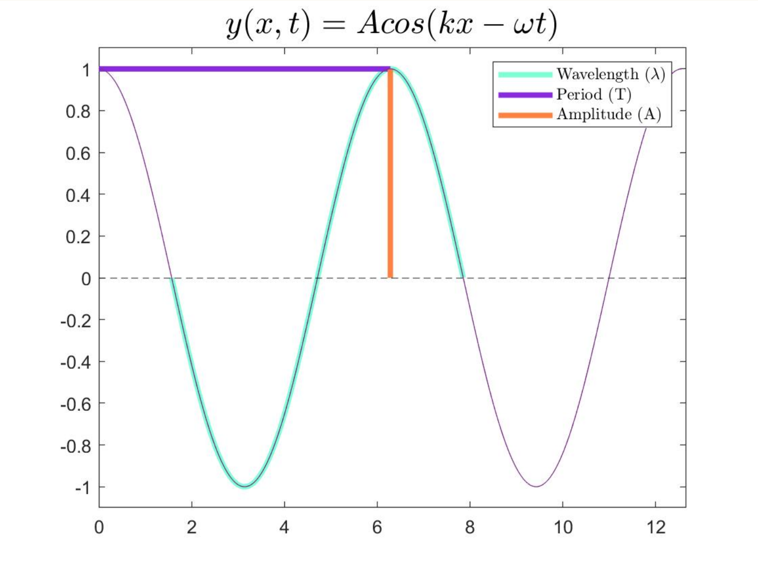
<u>Sound Waves</u>

A sound wave itself can be described as the movement of particles at a specific frequency such that it is audible. Sound is a longitudinal wave traveling through a medium like air or water. A longitudinal wave is when the medium moves rather than compresses the medium. A simple sound wave moves based on the following equation:

$$y(x,t) = A\cos(kx-\omega t)$$

- Where A is the amplitude (the height of the wave), or how much a particle moves from its position standing still.
- The variables y and x are displacements of the particle from its original position, where the wave is moving along the +x direction,
- while the variable, t, is time.
- The variable k is the 2π divided by the wavelength or equivalent to $2\pi/\lambda$
    - Note as the wavelength increases it decreases the k value and therefore the wave number decreases and as the wavelength decreases then the wave number decreases.
- Finally, ω or how long it takes the particle to complete one wavelength, $\omega=2\pi/T$, is the angular frequency

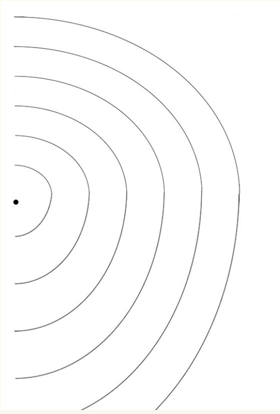
This equation is shown through the graph:



Sound is created by how a particle moves. The more distance the particle moves, the higher amplitude, the louder the sound is, while the smaller amplitude means a quieter sound. Another way for the sound to be varied is how long the wavelength is, the quicker the particle moves, the higher the pitch the sound is. The slower the particle moves, the lower the pitch of the sound. Think of this as how far the particle will move along its path in one second.

Propagation of Waves

Simple definition: the direction a wave moves away from its source. For sound waves, the propagation happens as wavefronts. The distance between each wave front is the wavelength of the wave. Each wave front pushes the sound from the source. Wave fronts take shape as arches and therefore as the sound gets further away from the source, the more area it can cover.



Resonance Box

Resonance is simply defined as the elongation of sound from reflections or neighboring objects vibrating at the same frequency. A resonance box is an instrument used to amplify a sound. Depending on the sound you want to be able to minimize or maximize the resonance. If you use a tuning fork you will use a resonance box to amplify it. On the other hand, if you are in a theater you need to minimize the resonance. Examples can be found everywhere: the human body, stringed instruments, and architecture

Human body

Two parts of the human body can act like resonance boxes. The first is the eardrum and here the ear canal is the resonance box. In the canal, the sound waves are amplified off the walls such that higher frequencies can be heard. Depending on the person, the ear canal is different sizes and therefore amplifies differently. In general, the smaller the ear canal, the better it is as a resonance box. The other is the vocal cords. When a human talks, they vibrate their vocal cords. The vibration of the vocal cords is amplified in the throat, mouth, and nasal cavity.

Stringed Instruments

String instruments are the best visual example of a resonance box. The sound originally comes from the strings and the different nodes created by the musician's hand. If the instruments did not have the body piece, the largest part of the instrument, there would be little to no sound being produced. The body of these instruments are resonance boxes. They are what allows the music to be produced from the strings. The body amplifies the sound that is produced by the strings. Examples can be seen in guitars, violins, violas, cellos, basses, ukulele, and charango.

<u>Architecture</u>

Resonance is affected by what is in the area. We can use a large room for example. When there is little or nothing in said room, it can amplify sound easily. You can think of it as the body of a string instrument. To be empty means it can amplify the sound easier. On the other hand, If you have a full room with different objects, this minimizes resonance. To visualize this, a music recording studio has carpets everywhere you look, this is because carpets are a good way to minimize the reverberations. When recording music you do not want to pick up any extra sound than what is wanted.

<u>Other Instruments</u>

Every instrument creates sound differently. The way flutes make sound is different from the way brass instruments make sound is different from the way drums make sound. Flutes produce sound when air is passed by the mouth hole. Based on the different types of flutes, the air passing by creates an airstream through the instrument. A modern-day flute has the keys to change where the air escapes from, while in a wooden or plastic flute you have to change the length of the cavity to change pitch. Either way, the pitch is changed based on how much/when air escapes the cavity. Brass instruments work based on the musician's mouth. They vibrate their lips to control the different pitches while the valves or slide is used to make minor adjustments when the note needs the same amount of vibration. Drums use the combination of surface area and tension to create sound. The different sizes of drums create different resonance boxes with the head. The head is made out of different materials and different sizes to change the sound. This is only the basics of how these instruments work.

<u>The Whistle Bottle</u>

A sound-producing instrument here at the museum is the whistle bottle. Using the replica allows for a visual of how it works. With the water inside the chambers, air flow becomes minimal. To play the instrument, with the water inside. You tilt the bottle back and forth. When this occurs the water inside the bottle displaces the air creating a vacuum. The air rushing out of the chamber(s) through the hole(s). To change the pitch the water level must change. This normally occurs as the ceramic absorbs the water. With less water, the pitch of the sound increases. When more water is added, the pitch lowers. Since the water is displacing the air, the air rushes past the water and out the small hole(s) in the chamber(s) where the water comes from. When the water moves back, more air is introduced into the system.

Citation

Young, H. D., Freedman, R. A., & Ford, A. L. (2020). *University physics with modern physics* (15th ed.). Pearson Education.

Appendix J: In-Depth of Physics Concepts Covered in the Program (Spanish Translation)

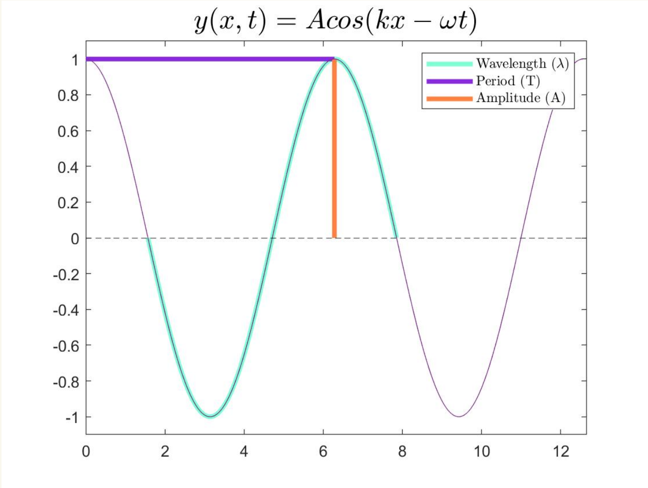
<u>Ondas Sonoras</u>

Una onda de sonido en sí puede ser descrita como el movimiento de partículas a una frecuencia específica tal que es audible. El sonido es una onda longitudinal que viaja a través de un medio como aire o agua. Una onda longitudinal es cuando el medio se mueve en lugar de comprimiendo el medio. Una simple onda de sonido se mueve en función de la siguiente ecuación:

$$y(x,t) = A\cos(kx-\omega t)$$

- Donde A es la amplitud (la altura de la onda), o cuánto se mueve una partícula de su posición de pie.
- Las variables y y x son desplazamientos de la partícula desde su posición original, donde la onda se mueve a lo largo de la dirección x positivo
- cuando la variable t significa tiempo
- La variable k es la 2π dividida por la longitud de onda o equivalente a $2\pi/\lambda$
    - Tenga en cuenta que a medida que aumenta la longitud de onda, disminuye el valor k y, por lo tanto, el número de onda disminuye y, a medida que la longitud de onda disminuye, el número de onda.
- Finalmente ω o cuánto tiempo tarda la partícula en completar una longitud de onda, $\omega=2\pi/T$, es la frecuencia angular

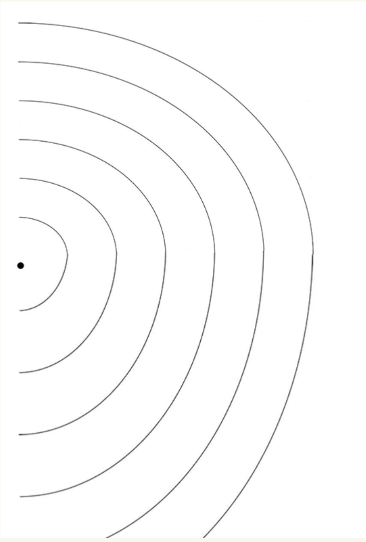
Esta ecuación se muestra a través del gráfico:



El sonido se crea por la forma en que se mueve una partícula. Cuanto más distancia se mueve la partícula, mayor amplitud, más alto es el sonido, mientras que la amplitud más pequeña significa un sonido más silencioso. Otra forma de variar el sonido es cuánto tiempo es la longitud de onda, cuanto más rápido se mueve la partícula, más alto es el tono del sonido. Cuanto más lento se mueve la partícula, menor será el tono del sonido. Piense en esto como hasta dónde se moverá la partícula a lo largo de su camino en un segundo.

Propagación de Ondas

Definición simple: La dirección en la que una onda se aleja de su origen. En el caso de las ondas sonoras, la propagación se produce como ondas efrontas. La distancia entre cada frente de onda es la longitud de onda de la onda. Cada frente de onda empuja el sonido de la fuente. Los frentes de onda toman forma como arcos y por lo tanto, a medida que el sonido se aleja más de la fuente, más área es capaz de cubrir.



Caja de Resonancia

La resonancia se define simplemente como la elongación del sonido de reflexiones u objetos vecinos que vibran a la misma frecuencia. Una caja de resonancia es un instrumento utilizado para amplificar un sonido. En función del sonido que desee, podrá minimizar o maximizar la resonancia. Si utiliza un diapasón de sintonización, utilizará un cuadro de resonancia para amplificarlo.Por otro lado si estás en un teatro necesitas minimizar la resonancia. Los ejemplos se pueden encontrar en todas partes: el cuerpo humano, los instrumentos de cuerda y la arquitectura.

El Cuerpo Humano

Hay dos partes del cuerpo humano que pueden actuar como cajas de resonancia. El primero es el tímpano y aquí el canal auditivo es la caja de resonancia. En el canal, las ondas de sonido se amplifican fuera de las paredes de tal manera que las frecuencias más altas pueden ser escuchadas. Dependiendo de la persona, el canal auditivo es de diferentes tamaños y por lo tanto se amplifica de manera diferente. En general, cuanto más pequeño sea el canal auditivo, mejor será como una caja de resonancia. La otra son las cuerdas vocales. Cuando un humano habla, vibrar sus cuerdas vocales. La vibración de las cuerdas vocales se amplifica en la garganta, la boca y la cavidad nasal.

Instrumentos de Cuerda

Los instrumentos de cuerda son el mejor ejemplo visual de una caja de resonancia. El sonido proviene originalmente de las cuerdas y de los diferentes nodos creados por la mano del músico. Si los instrumentos no tuvieran la pieza del cuerpo, la mayor parte del instrumento, habría poco o ningún sonido que se produce. El cuerpo de estos instrumentos son cajas de resonancia. Son lo que permite que la música se produzca a partir de las cuerdas. El cuerpo amplifica el sonido producido por las cuerdas. Los ejemplos pueden ser vistos en guitarras, violines, violas, cellos, bajos, ukelele, y charango.

Arquitectura

La resonancia se ve afectada por lo que hay en el área. Podemos utilizar una habitación grande, por ejemplo. Cuando hay poco o nada en dicha habitación, es capaz de amplificar el sonido fácilmente. Se puede pensar en él como el cuerpo de un instrumento de cuerda. Estar vacío significa que puede amplificar el sonido más fácilmente. Por otro lado, si se tiene una habitación completa con diferentes objetos, esto minimiza la resonancia. Para visualizar esto, un estudio de grabación de música tiene alfombras por todas partes, esto es porque las alfombras son una buena manera de minimizar las reverberaciones. Al grabar música, no desea capturar ningún sonido adicional, entonces lo que se desea.

Otros Instrumentos

Cada instrumento crea sonido de una manera diferente. La forma en que las flautas hacen el sonido es diferente a la forma en que los instrumentos de latón hacen el sonido es diferente a la forma en que los tambores hacen el sonido. Las flautas producen sonido cuando el aire pasa por el orificio de la boca. Basándose en los diferentes tipos de flautas, el aire que pasa crea un flujo de aire a través del instrumento. Una flauta moderna tiene las llaves para cambiar de donde sale el aire, mientras que una flauta de madera o plástico tiene que cambiar la longitud de la cavidad para cambiar el tono. En cualquier caso, el paso se cambia en función de la cantidad/cuándo escape el aire de la cavidad. Los instrumentos de latón funcionan sobre la boca del músico. Vibran sus labios para controlar los diferentes pasos mientras que las válvulas o el deslizamiento se utiliza para hacer pequeños ajustes cuando la nota necesita la misma cantidad de vibración. Los tambores utilizan la combinación de superficie y tensión para crear sonido. Con los diferentes tamaños de tambor crea diferentes cajas de resonancia y con la cabeza. La cabeza está hecha de diferentes materiales y diferentes tamaños para cambiar el sonido. Esto es sólo lo básico de cómo funcionan estos instrumentos.

La Botella Silbato

Un instrumento que produce sonido aquí en el museo es la botella de silbato. El uso de la réplica permite ver cómo funciona. Con el agua dentro de las cámaras, el flujo de aire es mínimo. Para tocar el instrumento, con el agua dentro. Inclina el biberón hacia delante y hacia atrás. Cuando esto ocurre, el agua dentro de la botella desplaza el aire creando un vacío. El aire que sale de la(s) cámara(s) a través del(los) orificio(s). Para cambiar el pitch, el nivel de agua debe cambiar. Esto ocurre normalmente cuando la cerámica absorbe el agua. Con menos agua, el tono del sonido aumenta. Cuando se añade más agua, el pitch baja. Dado que el agua está desplazando el aire, el aire pasa por el agua y sale por el pequeño agujero (s) en la(s) cámara(s) de donde proviene el agua. Cuando el agua retroceda, se introduce más aire en el sistema.

Appendix K: Data from 15 Museums

Museum	Rating	Is it Interactive? How?	How Informative is it?
Museum of Science, Boston USA	**5**	Yes, interactive experiments and equipment	Very, it covers a wide range of topics
Maryland Science Center, Baltimore USA	**5**	Yes, interactive exhibits and “enrichment experiences”	Very, especially science topics that are taught at local schools
National Museum of Play, Rochester USA	**5**	Yes, games	Yes, especially about games and their history
Providence Children’s Museum, Providence USA	**4.5**	Yes, interactive pieces/exhibits	Informative for very young audiences only
Getty Center, Los Angeles USA	**4**	Yes, thought-provoking questions	Very, it emphasizes critical thinking, interpretation, and conversation
Cuerpos Humanos Reales, traveling exhibit, seen in Cuenca, Ecuador	**4**	No	Very, good balance of visual and “cool” components
Deutsches Museum, Munich Germany	**4**	Yes, discussion and interactive pieces	Very informative and fairly high-level
Rockwell Museum, Corning USA	**3**	No	Somewhat
Smithsonian Museum of Natural History, Washington D.C. USA	**3**	Somewhat, supplemental activities online	Very, there is a wealth of information on a variety of topics
The Metropolitan Museum of Art, New York City USA	**3**	Yes, discussion	Very, especially scientific information
Worcester Art Museum, Worcester USA	**3**	Yes, discussion	Not broadly informative but good on science/art connection
Brooklyn Museum, New York City, USA	**2**	Yes, discussion	Somewhat
Field Museum, Chicago USA	**2**	Yes, virtual 3d models	Somewhat
The British Museum, London England	**2**	Yes, questions and group activities	Somewhat
Korea National Museum of Modern and Contemporary Art, Multiple Locations, South Korea	**1**	No	Somewhat