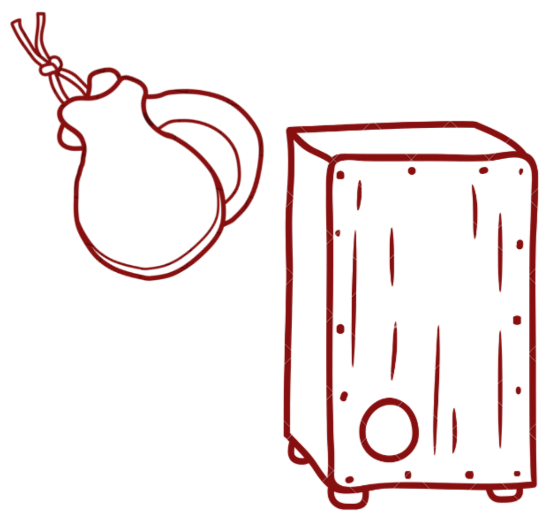
Harmonies of Andalusia

INTEGRATING FLAMENCO INSTRUMENT DESIGN WITH STEM EDUCATION

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 by

Molly Busby,
Gabriel Curet-Irizarry,
Nina Emens,
Ananya Gade
Date: May 1st, 2024



Approved:
Professor Nikitina Svetlana,
Major Advisor

Abstract

In collaboration with Dr. Lafuente at the University of Cádiz, we fabricated Flamenco-inspired instruments in the university's Fab Lab with the goal of exciting students about STEM while simultaneously integrating Andalusian culture. We consulted fabrication experts and visited various cultural landmarks to inform our work. The team successfully prototyped multiple versions of both a cajón and castanets and developed an education program to share the fabrication procedures with local educators so they could replicate a program in the Fab Lab.

Acknowledgments

We extend our gratitude to Dr. Luis Lafuente for his guidance, support, and insights throughout our research process.

Additionally, we would like to thank Ana Pilar, the Coordinator of the Degree of Engineering in Industrial Design and Product Development, whose expertise in fabrication techniques was pivotal in our exploration and implementation of various methodologies. Her mentorship and encouragement have enriched our learning experience immeasurably.

Furthermore, we extend our thanks to the students of UCA who generously shared their knowledge and assisted us in navigating the intricacies of the machinery. Special thanks to: Alberto Sierra, Irene Reche Bernal, Juan Carlos Calero, and Alejandro Rodriguez.

Additional acknowledgements to our advisors, Svetlana Nikitina and Kira Kovnat, as well as our ID 2050 Professor, Robert Hersh, for their support throughout our project.

Executive Summary

Under the guidance of Dr. Lafuente, an associate professor and the Dean of the School of Engineering at the Universidad de Cádiz, our project explored the innovative intersection of traditional Flamenco music and modern fabrication technologies. Fabrication Laboratories offer numerous benefits to students, significantly enhancing their educational experience while cultivating a maker mindset and interest in STEM fields (Rumpala, 2014). These labs provide access to advanced tools and technologies, fostering creativity and problem-solving skills and by engaging in practical activities, participants gain technical expertise and develop a passion for STEM fields. Dr. Lafuente proposed a project to build musical instruments within a Fab Lab utilizing machines like 3D printers, laser cutters, and CNC machines. His project vision emphasized music as a shared appreciation regardless of an individual's taste in music.

Our project aimed to lay the foundation for an educational program for middle school and high school students that integrated those principles of acoustics derived from physics, alongside technology, innovation, and music. Flamenco, recognized for its deep emotional and cultural expression, uses instruments like the cajón and castanets that have evolved over centuries. Simplistically, the modern version of a cajón is a wooden box that is entirely enclosed aside from the hole in the back. In terms of its acoustic construction, the front panel of the drum is thin compared to the other panels and is loosely attached to create a "snare effect". Castanets are a traditional Spanish percussionist instrument, a set of clappers where one side rests on the palm and the other side is looped around the thumb. These are then used alongside the basic rhythm of the song by flamenco dancers. The sound of castanets depends heavily on how it's sized and carved out ("*How Castanets",* 2024*)*. The program not only introduces students to the principles of acoustics and music but also embeds the technological processes of instrument making.

Our goal for this project was to prototype musical instruments inspired by Flamenco that use various Fab Lab machinery. During our seven weeks of fieldwork, we identified optimal materials, modeling software, and Fab Lab machinery to fabricate working musical instruments. We developed and organized a complementary program for middle and high school students to recreate these instruments at the University's Fab Lab. This program was intended for educators to use and refine in the future:

To accomplish this we took certification courses including basic user training, laser cutters, and 3D printers. Such tangible experience aided us in designing 3D models that we

converted into machine-compatible files for facilitating the fabrication of physical functional instruments. In parallel, we consulted with Fab Lab technicians to refine our ideas and understand the full capabilities and limitations of the available machinery. This collaborative approach ensured that our prototypes were both innovative and feasible within the given technical constraints.

The main outcome of the program was for students to create a working, playable instrument. We also included topics of music theory and Andalusian culture. We workshopped a program demonstration to gather insight and feedback regarding suggestions for improving the specifics of the program. We conducted surveys regarding their musical interests, and level of STEM knowledge, and provided them with the space to identify anything they may be interested in making. We hosted a workshop on April 18th that demonstrated the possibilities within the Fab Lab for the program. We analyzed the data from this form to determine the most inclusive and engaging educational program for our demographic.

After identifying and experimenting with suitable Flamenco musical instrument design in the Fab Lab, the team was able to successfully develop playable castanets and cajóns. We attended Flamenco shows to analyze the rhythms and harmonics of authentic instruments. We expanded our use of tools within the Fab Lab by fabricating a resin castanet using silicone as a negative, reusable mold.

Our changes and recommendations for the castanets are as follows:

1. Due to the time it takes for the resin to dry, we would make a mold that can hold the castanet pairing so that each piece does not need to be made individually.
2. Measure out the ideal size of the box rather than using the readily available wood.
3. It is important to ensure that the castanet stays straight within the wooden box.

Our changes and recommendations for the cajóns are as follows.

1. The laser cutter does take off a bit of excess wood so that is important to account for when sizing the cajón. The team found that running the laser cutter twice over the same section is also helpful when it comes to cutting the wood.
2. Having multiple clamps (8+) is crucial to maintain the integrity of the cajón shape. We found that the smaller clamps to be more useful than the larger.

For future WPI students continuing this IQP project we recommend setting more time aside than necessary for completing fabrication tasks. From our group's experience in the Fab Lab we have learned that the machines including the Laser Cutter and 3D printer are inconsistent. There were times when the machines malfunctioned and set our time line back. Additional advice for future Fab Lab groups is to construct a list of necessary project materials during ID2050 to send to your sponsor to order before you arrive at the Fab Lab. By doing so, students can ensure that necessary materials are ordered well in advance, minimizing fabrication delays.

Furthermore, fostering a relationship with students and professors in the Fab Lab and establishing channels for communication is extremely important. The students and professors at the University of Cádiz helped us greatly with learning the machines available in the Fab Lab and navigating setbacks during fabrication. Without establishing these relationships in the first week we would not have been able to accomplish as much as we did.

Lastly, we encourage future project teams to maintain a flexible and adapting mindset when approaching their fabrication tasks.

Authorship

Each person in the group researched valuable resources for the background and methods chapter. We sat down each time as a team to draft what to include in each section and each individual included their researched materials based on relevance. We felt that it was important for all team members to revise and review sections in their entirety.

For the results, discussion, and conclusion the team split tasks accordingly based on strengths. Ananya was the primary writer for the executive summary and canva designs. The team worked together to build the instruments. Molly was the primary writer for the results and instrument procedures. Nina and Gabe were the primary writers for the software procedures and conclusion.

Table of Contents

List of Figures

Introduction: Musical Instrument Fabrication in a Fab Lab

Fab Labs, short for Fabrication Laboratories, serve as small-scale workshops utilized for digital fabrication. They operate as a platform for broader participation and new ways of collaborative engagement in design and innovation. Fab Labs offer numerous benefits to students, significantly enhancing their educational experience while cultivating a maker mindset and interest in STEM fields (Rumpala, 2014). The maker mindset is a hands-on approach to problem-solving. Through interactive learning activities, students gain practical skills in problem-solving and critical thinking (Dougherty, 2013). These labs provide access to advanced tools and technologies, fostering creativity and problem-solving skills. By engaging in practical activities, participants gain technical expertise and develop a passion for STEM fields.

Our sponsor, Dr. Lafuente, is an associate professor in the Math Department at the Universidad de Cádiz and also serves as the Dean of the School of Engineering. Dr. Lafuente founded the Fab Lab at the University of Cádiz. With a background in classical piano and music theory, Dr. Lafuente proposed a project to build musical instruments within a Fab Lab utilizing machines like 3D printers, laser cutters, and CNC machines. Dr. Lafuente's project vision emphasizes music as a shared appreciation regardless of an individual's taste in music. This program aimed to be inclusive, welcoming students of all cultural and educational backgrounds. The structure of this program is designed to accommodate students who can't attend full time education, providing STEM opportunities not previously accessible.

Our project aimed to lay the foundation for an educational program for middle school and high school students that integrates the principles of acoustics derived from physics, alongside technology, innovation, and music. Many young children in less affluent families do not have access to educational programs or have to pursue work to support their family over a higher education (Soret, 2019). By teaching technical skills through the fabrication of musical instruments, we hope that the students develop a lifelong interest in both fields, thereby leading them to pursue further studies or careers in STEM professions, music, or interdisciplinary fields. Additionally, the program will simultaneously create a culturally enriching experience on the culture of Andalusia and the tradition of Flamenco.

Background: Flamenco Instruments, Musical Education in Andalusia, and the Rise of Makerspaces

Musical Instrument Design, Sound - Aesthetics and Kinesthetics

Physics concepts can be applied to music making by studying the oscillating waveforms of the vibratory movement of the instruments through time. Such concepts are vital to understanding how to tune instruments to create good sound as well as the basis of how our brain interprets sound. The fundamentals of acoustics consist of sound, frequency, and pitch. Sound is created from small fluctuations in air pressure and frequency builds off of those fluctuations by creating vibrations through a series of pressure waves. Frequency accounts for the number of vibratory cycles per second. Instruments with low frequencies are typically associated with room-filling bass sounds while instruments with high frequencies are associated with narrow-angled trouble sounds (See Figure 1). Different vibrations have different waveforms. For example, single frequencies have smooth curves while strong harmonics have angular, rectangular forms. There are 3 factors in most oscillations: displacement, restoring force, and inertia. Frequency calculations are dependent on the intensity of the restoring force as well as the inertia (Hopkin, 1996). Overall, these concepts are important in building one's understanding and proficiency of instrument design.

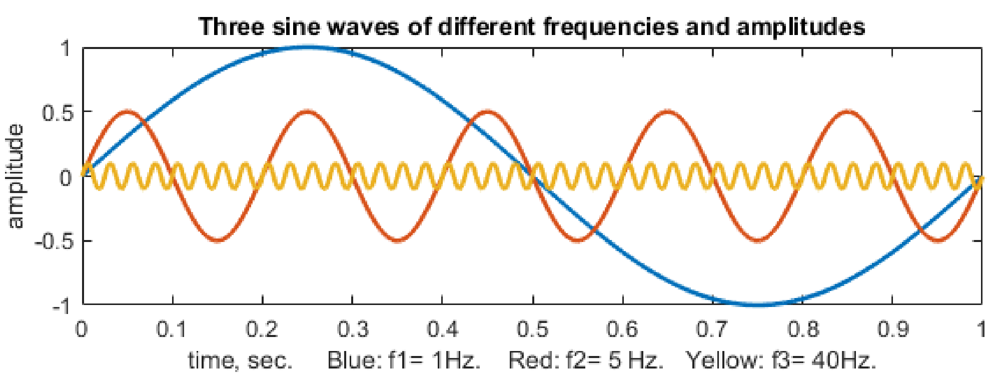


Figure 1: Waveforms of Varying Frequencies ("Intro")

A pitch is a sound vibration that comes from a single steady frequency. Musical instruments utilize a blend of frequencies, called timbres, to make sounds. Some instruments have no steady frequency present while others have several steady frequencies present that blend as a single tone. "Pitchless" percussion instruments have an ambiguous pitch, which means they essentially have no pitch. Another important component of pitch is the relationship between the instrument and the musician. Ergonomics and gestures are vital components affecting the sound. This includes the comfort of the playing position and observing visual effects like beauty and gracefulness (Hopkin, 1996). Understanding the kinesthetics and aesthetic effects on music-making is just as important as the construction of the instrument itself.

The History of Flamenco Instruments and Music

Percussion and string instruments are the most common instruments used to support Flamenco artists, specifically the cajón and castanets. These instruments will be part of the design objective, thus a knowledge of their cultural history and construction is critical in the success of the project.

Construction of Flamenco Instruments

A cajón is a percussion instrument that has been incorporated into Flamenco music over the centuries. Musicians originally sat on crates to make the rhythmic patterns. In Spanish, cajón, or caja, is translated literally to mean "crate". Simplistically, the modern version of a cajón is a wooden box that is entirely enclosed aside from the hole in the back (See Figure 2). They are normally about "half a meter tall and 30 cm wide and deep" (Ludwigsen, 2015). In terms of its acoustic construction, the front panel of the drum is thin compared to the other panels and is loosely attached to create a "snare effect". The snare sound can also be created with wires or guitar strings inside of the front panel. The cajón can create a wide range of tones based on where it is struck and the method of how it is struck. The middle of the panel produces the bass tone while the upper edge produces a higher tone. Using an open palm can produce a short, deep tone while fingertips make more delicate tones (Ludwigsen, 2015).

Traditionally the cajón is made from denser solid hardwood. This can be locally sourced; there isn't necessarily a 'best' wood for this. Some examples of the wood are wengre, padouk, walnut, oak, maple, and redwood (*"Best")*. Recycled hardwood could also be used, and is a more sustainable option, however, it is important to make sure the wood should be dried or it increases the risk of splints. Plywood is also another option for the cajón. However depending on where this is sourced, it could be a more expensive option. Flamenco cajóns have 2 to 10 guitar strings inside the cajón (Bill, 2020). Although these strings are usually regular guitar strings, they can also be made out of beaded wires, and curly snare-type wires. Some cajóns can be adjusted to tune the strings. Cajóns also have a brace located in the inside corner of the instrument. It's essentially a wooden panel that is added to strengthen the instrument. It can vary based on how and what kind of wood is utilized (Bill, 2020). The knowledge of this construction will be utilized to inform the prototyping phase of the project, specifically in terms of the woods which can be used and the development of snare strings.

Figure 2: Visualization of cajón ("Team", 2018)

Castanets are a traditional Spanish percussionist instrument often made from ivory or hardwood. The word itself is derived from the Spanish castina meaning chestnut. Castanets are a set of clappers where one side rests on the palm and the other side is looped around the thumb (See Figure 3). These are then used alongside the basic rhythm of the song by Flamenco dancers. The smaller ones, typically worn by women, create a higher crisper tone called hembra. Men wear a larger pair called macho that produces a lower, richer tone.

Figure 3: Visualization of Castanets (Katie, 2024)

The best wood for castanets is often very hard such as oak, ebony, grandillo, or rosewood. However, sourcing this wood can become expensive and seen as unsustainable. Alternatives like micarta have been sought out. Micarta is essentially a cloth material that has been made by fusing many layers and adding a resin. The sound of castanets depends heavily on how it's sized and carved out ("*How Castanets",* 2024*)*. The knowledge of this construction will be utilized to inform the prototyping phase of the project, specifically in terms of the castanet's shape which is crucial to its sound and resonance.

See Appendix A for an extended list of instruments that either originated or are commonly used to accompany Spanish music.

Brief History of Flamenco

Flamenco is a very important part of Andalusian culture. It is important to acknowledge and understand the integral parts of it in order to adequately assess cultural components and how to implement them into a program. Flamenco is both a form of song and dance with its foundation in "cante". In the 1400s, flamenco had no supporting instruments or dancers to support the vocal music. By the 1700s, it became common for the guitar and dancers to accompany the vocals. There is a heavy emphasis on gesture, footwork and posture in flamenco music. In the current day, the three main disciplines of flamenco include: "cante" (song), "toque" (guitar-playing), and "baile" (dance) (Romero, 2021). There are 3 subcategories of cante which include: cante jondo, cante intermediate, and cante chico. Cante jondo, "profound song", is the oldest form of flamenco based on a 12-beat rhythm that is characterized by themes of death, despair, religious doubt, and more. Cante intermedio, "intermediate song" incorporates fandango which is another genre of Spanish folk songs. Cante chico, "light song", requires more technical skill than the other styles, but less emotion because it deals with themes of humor, love, and the countryside (Gaur 2023). There are over 50 different flamenco styles, called palos. The most important palos are called tona, solea, fandango, and seguiriya which all fall under cante jondo. Bulerias and tangos fall under cante intermedia. alegrias, fandangos, farruca, guajiras, sevillana, and verdiales fall under cante chico (*"Flamenco",* 2005).

Toque utilizes altered chords containing non-triadic tones to complement the cante. This is important because it helps introduce the expressiveness and emotions that the vocals aim to do (Manuel, 1986). The dances are typically improvised and tell the stories of the daily life of outcasts in a predominately white, Christian Spain. This storytelling is influenced by the Moorish people who resided in Spain before the Spanish Inquisition. Moorish musicians sang about the adversities they faced while living in Andalusia. Such concepts are reflective of the gestures performed in the baile during cante jondo and cante chico. It is common for Flamenco dancers to fall into a"duende", a type of trancelike state within the body after dancing for 15-20 minutes (Gaur, 2023). Flamenco is an overall expressive and emotional form of art. See Appendix B for more information regarding the origins of Flamenco and its musical influence throughout time.

Carnival

Another culturally important event in Spain is the Cádiz Carnival which takes place 40 days before Easter and lasts a whole week. Street celebrations include parades with floats incorporating music and other shows. People dress up in colorful costumes and masks. The Carnival of Cádiz is distinguished by its fun tone, chirigotas and comparsas. Comparsas are people in disguise who walk through the streets singing humorous songs. Chirigotas are popular singing groups originating from the region of Andalusia, made up of between 10 and 20 members dressed in flashy and colorful costumes. One of the most emblematic elements of the chirigotas is the pito las chirigotas. This wind instrument is a four-tone whistle that the members of the group use to mark the rhythm of the songs. This instrument is also known as a carnival flute, mirlitón, carnival turuta, pito de caña or kazoo. The use of this instrument in Spain's

Carnival dates back more than 100 years. At that time, carnaval musicians used different types of instruments such as flutes, guitars and drums. The carnival flute became the most popular instrument due to its ease in creating different tones and melodies. Due to its overwhelming popularity local merchants saw the opportunity to sell these wind instruments to tourists and local travelers, making the carnival flute the most profitable instrument for Cádiz year round. These whistles usually are made of metal or plastic and produce a high-pitched, shrill sound when blown into it. To incorporate more components of Andalusian culture, we aimed to produce these flutes in the Fab Lab.

Figure 4: Visualization of Carnival Flutes (Miller, 2013)

Musical Education in Andalucia

Traditional flamenco music has made a significant impact on the Andalusian region, and therefore their education system. While flamenco is embedded in the content of Andalusia's educational curriculum in most Spanish history classes, There is a lack of musical education as a whole (Cuellar-Moreno, 2016). Beyond an instructor's capability to set their teaching agenda, a common reason for the decline of music education is due to conservative pressures. Non-STEM subjects are not perceived as relevant for the labor market so music is seen as merely a task useful to amuse students. As a result, some students will not receive artistic education during all their compulsory schooling (José, 2016).

Integrating flamenco into the curriculum contributes to a deeper understanding and appreciation of the cultural heritage of Andalusia. For example, an educational program at the University of Murcia was adapted by Jose Francisco Ortega Albaladejo to focus on Flamenco music theory. This course analyzes the musical characteristics of Alegrías, a folk singing (Cante) representative of flamenco from Cádiz, including rhythm, melodic organization, harmony, and form. Students learn about the rhythm of Alegrías by playing small percussion instruments including claves, cajas chinas, orffs, and recorders. A poll revealed that the majority of students were more interested in flamenco by the end of the course, and their instructor saw that most of the students became more proficient with their musical instruments (Ortega, 2020). Approaches like Ortega's not only help prevent flamenco from being relegated to the periphery but also underscore its importance as a vibrant cultural phenomenon worth exploring within the broader educational framework (*Temporalización, 2021*).

Cristina Vasquez, a student and a violinist from an underprivileged community in Madrid, Spain, lead the project "Music of Recycling", which is an orchestra made from trash and recyclable materials. The instruments themselves were created by Fernando Soler, a third-generation instrument maker. While not traditional instruments, they were created to mimic the instrument's sound as closely as possible. This project allowed students to play instruments they would not have had prior access to. Access and support towards such opportunities allow these students to explore their passion, and keep them "straight and narrow in a neighborhood" with a high dropout rate (Sar, 2013). Similarly, our project hopes to provide such opportunities of pursuing a higher education in a STEM career.

Hands-On Learning

Musical education emphasizes hands-on experience rather than lecture-based curriculum. Such an approach can spark interest through collaboration and joint learning. Fabrication laboratories and maker spaces have provided unique space to apply this hands-on, experimental approach. A few studies have demonstrated this success:

In a study conducted in Hong Kong, a "flipped-classroom" setting was utilized to teach music, specifically Shubailan, by encouraging students to learn music theory outside of the classroom and gain hands-on experience in class. This online setting created a dynamic and collaborative environment in that classroom by focusing on hands-on activities in person. The researchers conducted interviews and found that there was an overwhelming number out of 122 students who indicated that they were excited to learn the theory outside of class. See Appendix C for the positive statements that students made regarding their hands-on learning experience. Overall, they enjoyed the flexibility to learn at their own pace with the opportunity to rewatch videos and take breaks as needed. The fundamentals further helped their understanding of class lessons and made the face-to-face time more productive and interesting (NG et al, 2022). In our specific project, when constructing an educational program that integrates both the history of music with the components of STEM, creating a dynamic environment is vital based on student input. It is important to make the most out of the time in the classroom by creating deliverables that can be taught outside of the classroom and built upon through projects. Hands-on learning builds collaboration and a sense of fulfillment in students.

Another study conducted by Thomas Regelski at Helsinki University in Finland highlighted the need to promote participatory activity when it comes to music education. Regeleski found that hands-on activities serve as a valuable tool for enhancing interpersonal skills, fostering dialogue on diversity, and contributing to positive societal interactions. Gaining positive musical experiences, in which an intersubjective connection between participants is achieved, encourages the creation of new links to interrelations, which in turn enhance the coexistence between people (Cabedo-Mas et. al, 2016). Collaboration is the other component beyond hands-on learning that has been established as crucial in the success of experimental-based learning programs.

Examples of Musical Instrument Fabrication by Students

Hands-on learning is applied and implemented in instrument fabrication in addition to musical education programs.

A study was conducted at three multilingual schools in Canada observing the practices and methods of fifth-grade students making and playing. Hagerman found that the students' making was shaped by their understanding and relationships to school and learning. The project combined online reading and research strategies with hands-on building opportunities. The students were tasked with designing and building a new instrument integrating properties of current instruments in terms of sound and structure. About 20 students participated and a few were interviewed regarding their workflow process. Overall, the researchers found the main similarity between all of the students to be collaboration. They found that it was fundamental for the students to interact with each other to further their innovation process. This case allowed the students to have entire creative freedom over their project only limited by their imagination and a specific list of materials. Students felt encouraged and inspired to complete their project as their goal was not constrained to a strict set of guidelines (Hagerman, 2022). While the students are a grade younger than those of our program, we can make use of these insights. Understanding how students work is crucial to the success of a project-based learning approach.

Another study conducted in December 2023, looked at how 3D printing various parts of a guitar can affect the vibrational characteristics of the instrument. The use of additive manufacturing (*"AM"*) which is essentially building something layer by layer allowed for more complex shapes. This also means that guitars and other instruments can be created using non-conventional shapes however aiming to produce similar sounds. This is done by running simulations to test the acoustic properties of the instrument. This allows an understanding of how the AM can be utilized to get the desired outcome. It can also allow for customizations and modifications as wanted in the instrument. The study analyzed how printing direction can affect the sound the instrument produces. Various sketches outline the various angles at which this guitar body could be printed. (Bragaglia et al, 2023). Overall, the study found a unique way to approach musical education in terms of music theory and engineering. Another component to be aware of for this project is unique ways to integrate STEM into the instrument and the educational program. Integrating music theory and applications of physics could serve as such an objective. Although additive manufacturing could be more complex in terms of usage of materials, 3d printing primarily focuses on building something in layers. This would be useful for building our kazoo as it allows us to understand how 3D printing the instrument would affect the sound it produces.

The Expansion of Fab Labs and Maker Spaces

While experimental learning can be implemented in any classroom, there have been further developments that designate a space specifically made for hands-on learning through collaboration and "making". Fab labs and maker spaces are frequently seen as innovation centers, with the shared objective of encouraging creativity and discovery. While they share a dedication to innovation, fabrication laboratories are distinguished by their extensive technical infrastructure, which includes cutting-edge tools and resources for prototyping and production (Rumpala, 2014). Despite various levels of technical expertise, they are considered equal in their primary function of stimulating and driving innovation.

Fabrication Laboratories serve as small-scale workshops utilized for digital fabrication. They operate as a platform for broader participation and new ways of collaborative engagement in design and innovation. Fab Labs are more than just places to make things. They are places where people come together to build communities, collaborate, and create opportunities. Where they can share the knowledge they have learned and empower individuals from diverse backgrounds. Fab Labs are typically equipped with 3D printers, CNC machines, laser cutters, high-resolution milling machines, electronics, microprocessors, and much more (see Appendix D) (Kontogeorgakopoulos, 2019). The earliest Fab Lab was established in 2002 in Norway and named MIT-Fab Lab, as a collaboration between Fab Lab Norway with MIT - Massachusetts Institute of Technology Department; Center for Bits and Atoms. The founder of The MIT Fab Lab, Neil Gershenfeld defines Fab Labs as “high-tech, low-cost workshops, equipped with the tools to make almost everything…” (CNN, 2008; Kohtala et. al, 2014).

In addition to the growth of Fab Labs, universities all around the world have begun to incorporate similar courses to the MIT course into the curriculum. For example, the Dublin Institute of Technology recently developed an elective course called “Fab Lab: What Do You Need to Make (Almost) Anything?”. The elective was highly popular with students and led to more Fab Lab courses and workshops at the university. Faculty at Dublin Institute of Technology believe that the course acted as a catalyst for increasing student creativity, innovation, and community (Sar et. al, 2013). By working on these projects the students carry what they learn in the Fab Lab to their everyday lives, be it by using the artifacts they built there or using the newfound logic and applying it in other areas. The collaborative environment is essential for promoting creative thinking, communication, and teamwork skills. The Fab Labs help spark excitement for learning and increase the innovation spirit of students (Othman et al., 2022). Neil Gershenfeld explains “What really drove the success of the SETC lab, and all the fab labs, is the passion to create. There’s a passion to make from bright, inventive people, who often are refugees from very rigid schools or companies who are attracted. They get pulled in for the capabilities but stay for the culture” (CNN, 2008; Kohtala et. al, 2014). These studies have found many positive influences regarding experiences in Fab Labs for students.

Educational Benefits & Maker Mindset

Fab Labs offer numerous benefits to students, significantly enhancing their educational experience while cultivating a maker mindset and interest in STEM (Science, Technology, Engineering, and Mathematics) fields. The maker mindset is a hands-on approach to problem-solving and creative pursuits. It is a combination of natural interest in how things work, as well as the desire to investigate new concepts through technology. Fab Labs provide students with hands-on learning opportunities that are essential for deepening understanding and the retention of concepts. Through interactive learning activities, students gain practical skills in problem-solving, critical thinking, and a maker mindset, which are highly valued in today's rapidly evolving technological landscape (Dougherty, 2013).

Fab Labs enable students to implement their ideas and create a sense of agency and ownership in their learning process by providing an assortment of tools, materials, and technologies they can use. This hands-on approach not only piques students' interest, but it also builds confidence through physical results. These spaces also play a crucial role in destigmatizing access to STEM education by breaking down barriers and welcoming students from diverse backgrounds and skill levels. By providing an inclusive and welcoming space, they inspire a sense of belonging and community among students, encouraging them to explore new interests and pursue STEM-related activities with enthusiasm (Othman et al., 2022). In addition to individual skill development, maker spaces also promote collaboration and teamwork. Students can work together on projects, share ideas, and learn from one another. This collaboration further fosters a culture of innovation and creativity, where students feel empowered to push the boundaries of what is possible. With our program, we hope that students develop a lifelong interest in STEM by learning technical skills through the fabrication of musical instruments, thereby leading them to pursue higher educations

Examples of Courses Integrating Fab Labs

Beyond college universities, many elementary schools have also adopted Fab Lab courses to help spark students' excitement for innovation and learning at an early age. A few studies regarding both successful Fab Labs and maker spaces are recorded below:

A study of 39 students in Europe analyzed whether a Fab Lab could foster an interest in science classes in younger students. Teachers in this study were tasked with creating learning outcomes that were attainable for students. The main project entailed designing a prototype using 3d printers within a collaborative team of students. There were various parts to the project giving the students hands-on experience with the printing software. Overall, the results found that students showed more engagement and excitement about learning in a Fab Lab. The project promoted creative freedom and collaboration among students with hands-on learning (Togou, 2020). While the school did not have a fully established lab, the study demonstrated that the fundamental principles of the Fab Lab foster an inclusive environment for STEM interests.

This study's main focus was to see how integrating Fab Labs and Makerspaces in schools (K-12) can ensue better student confidence and overall performance. They created an assessment called EFT to test exploration and fabrication technologies available at the schools. The hope was to create a better way to gauge the technologies available at these institutions. This was implemented at 5 different schools in 3 different countries. There were multiple iterations of surveys done over several years (2012 -14) The schools themselves differed from private to public, in grade level, and socioeconomic status. This provided a more diverse set of responses to this assessment. The ETF measures both confidence and performance. There are several charts to see the exact breakdown and the schools that participated in this study (Blikstein et al, 2017).

Researchers also have studied how to integrate musical instrument fabrication in a Fab Lab. The Game|Lan research project was conducted in 2019 and took place at three Fab Labs in South America, the Fab Lab at the University of Chile in Santiago, the Fab Lab Lima in Peru, and the Fab Lab of the National University of Colombia Medellin. The project hoped to explore the capabilities of the Fab Lab network by collaboratively designing and creating a small orchestra of digitally fabricated musical instruments (Kontogeorgakopoulos, 2019). The concept of the project was to co-design and co-fabricate a series of elegant and simple, digital musical instruments for non-musicians. The Labs aimed to develop an instrument that combined their local cultures and geographical locations. After a total of three weeks, each group successfully contributed to the design and fabrication of one finalized MIDI instrument with a polyhedron shape that triggers a different musical phrase when each side is hit. Not only was this study successful in creating a musical instrument inside a Fab Lab it also allowed the people involved to share knowledge, skills, and ideas beyond their cultural barriers.

In conclusion, the integration of Fab Labs and Maker Spaces in educational settings, ranging from elementary schools to higher education institutions, has shown promising results in fostering student engagement, creativity, and collaborative learning. Importantly, these studies showcase how such educational initiatives can transcend cultural and geographical barriers, encouraging knowledge-sharing, skill development, and idea exchange among diverse groups of individuals.

Methodology: Field Work and Interviews

Our goal for this project was to prototype musical instruments inspired by flamenco that use various Fab Lab machinery. In addition, we designed an educational program based on our fabrication techniques, flamenco music theory, and Andalusian culture. During our seven weeks of fieldwork, we identified optimal materials, modeling software, and Fab Lab machinery to fabricate working musical instruments. We developed and organized a complementary program for middle and high school students to recreate these instruments at the University's Fab Lab. This program is intended for educators to use and refine in the future. The educational program also aims to foster a deeper appreciation of flamenco, an important component of Andalusian culture, by enriching students' understanding of its history and music fundamentals. Our research objectives and how we accomplished them are shown in the flowchart below (see Figure 5):

- Identify a suitable flamenco musical instrument design.
- Explore and experiment with fabrication possibilities.
- Develop an educational program based on our prototype fabrication.

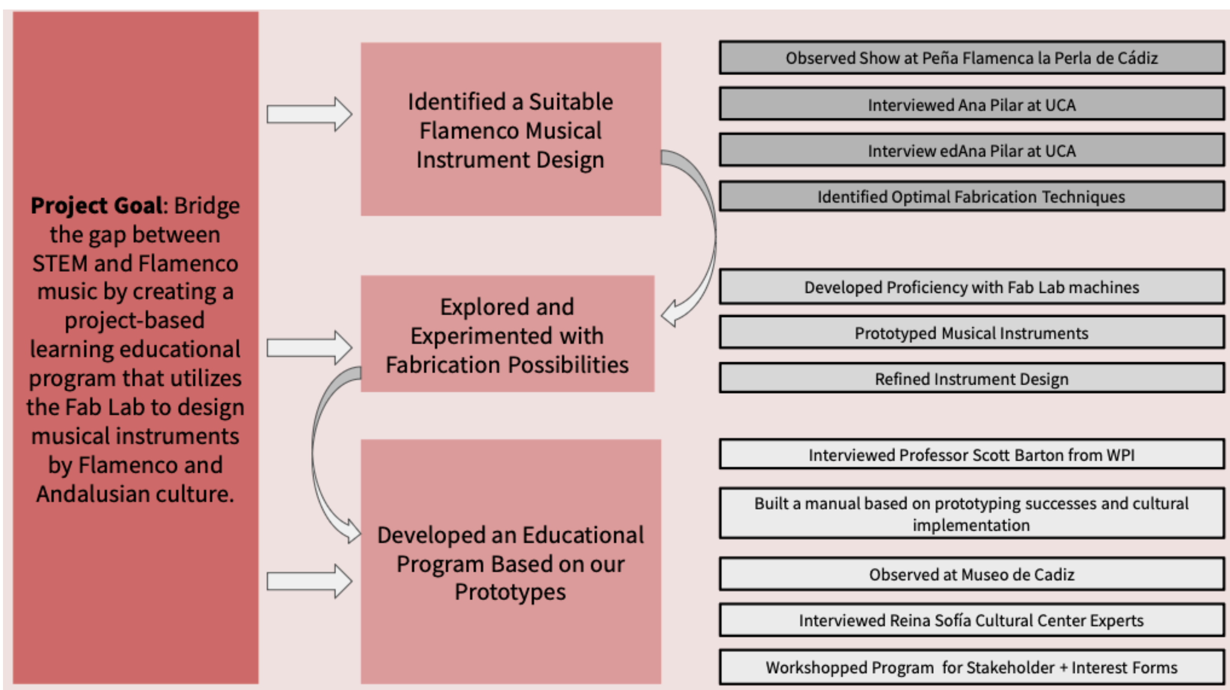


Figure 5: Goal and Objectives Chart

1.1 Identify Optimal Flamenco Musical Instrument Design

To best understand the construction of Flamenco instruments, we conducted research through observation and interviews. To better understand the art of Flamenco, we observed a show at the Peña Flamenca la Perla de Cádiz, a music venue in Spain home to many local Flamenco artists and groups. As part of this observation, we documented the types of instruments used and the styles of Flamenco incorporated. We also conducted interviews in Cádiz, Spain with engineering professors and students working in the Fab Lab at the University of Cádiz. We worked closely with Ana, a professor working in the Fab Lab. Ana was familiar with the technology, equipment, and materials available in the Fab Lab. She taught and ran demos on how to use the laser cutter and the 3D printer. She also helped us set up the silicone mold for the resin castanet. Overall, she was our main resource to guide us through how to best utilize the machinery for our project. Along with Ana, there were a group of university students in the Fablab that were simultaneously working on their project. They were also incredibly helpful in giving us ideas and helping us with technology. Interviewees were provided with an Informed Consent Form (Appendix E) and asked questions about craftsmanship specific to the Fab Lab, related challenges, and ways to incorporate Flamenco design into our instrument. The students and professors associated with the Fab Lab at the University of Cádiz provided us with insight into fabrication ideas and techniques using the various machinery. The data we collected from interviews was used to further develop our design process. Appendices F and G include a preliminary list of interview questions for the University faculty and students.

1.2 Explore and Experiment with Fabrication Possibilities

We utilized information from background research as well as materials recommended in interviews to begin our design process. Our team reconvened with Dr. Lafuente and Ana Pilar to determine the most accurate sketches of the instrument(s) for manufacturing. Dr. Lafuente provided us with an extensive list of machines and materials located within the Fab Lab (see Appendix H). We created a materials list with the quantities necessary after performing a field assessment of current materials in the Fab Lab see Appendix H). Before fabricating, we needed to become familiar with the machinery and machine-compatible systems in the Fab Lab to implement our design sketches. To accomplish this we took certification courses including basic user training, laser cutters, and 3D printers. In addition, we learned the basics of the design software SolidWorks through watching educational videos and demos. Such tangible experience aided us in designing 3D models that we converted into machine-compatible files for facilitating the fabrication of physical functional instruments.We successfully edited and refined STL files for a carnival flute and castanets that are compatible with all the 3D printers in the lab.

After our design sketches (see Appendix I) were consolidated, we prototyped our instruments . In our first month, we successfully developed prototypes for the cajón and castanet. By the end of our second month, we refined our prototypes and finalized our instrument designs. We used photo-documentation methods throughout our prototyping to assess our progress as well as reference past work when making revisions.

1.3 Develop an Educational Program Based on Our Prototype Fabrication

Alongside refining our instruments, our second month in Cádiz focused on designing our educational program based on fabrication, cultural appreciation, and collaborative learning upon completion of instrument prototypes. We designed a curriculum and a working product demo to complete this objective. To understand successful course teaching, we interviewed Professor Scott Barton from WPI who teaches a program at WPI called “Making Musical Instruments”. His collaborative, project-based course explores the principles involved in instrument design with the end goal of using unconventional materials/techniques to make new and innovative instruments. Professor Barton had critical insight into what the implementation of the design phase of our project could look like within a program, from not only his vast experience teaching this course but also his experimentation and research on instrument design. Professor Barton was provided with an Informed Consent Form (Appendix E) and Appendix K consists of the list of questions we asked. We utilized his knowledge and insight to structure our program. The main goal of this program is for students to create a working, playable instrument. The program was designed to accommodate 5-8 students for 90-minute sessions over 10 class sessions. See Appendix J for the template lesson plan we created for the future program.

Alongside the goal of teaching hands-on learning, we included topics of music theory and Andalusian culture. We further divulged into the history of musical instruments relating to Flamenco. To gain a holistic experience of Flamenco and Andalusian culture in Cádiz, we conducted further ethnographic research through interviews and observation to incorporate into our educational program. One historical center we visited is the Museo de Cádiz. Here we observed cultural artifacts native to Cádiz and obtained a deeper knowledge of Andalusian history. We also conducted interviews with cultural experts in Cádiz at the Reina Sofia Cultural Center to learn the extent of culture taught in the education systems here in Cádiz. Interviewees were provided with an Informed Consent Form (Appendix E) and were asked questions specific to Flamenco's rich history, education in Cádiz, and components of Andalusian culture. See Appendix L for a comprehensive list of interview questions. The knowledge we collected from interviews was incorporated into our program.

In the last weeks of our project, we conducted a focus group with the students to whom the educational program is catered. A crucial component of the success of this project was to understand how to make a program that connects with students. We conducted surveys regarding their musical interests, and level of STEM knowledge, and provided them with the space to identify anything they may be interested in making. We worked with the university liaison at the University of Cádiz to create and distribute an anonymous interest form for middle school and high school students regarding their general interest in fabrication and music. We hosted a laser-cutting workshop to demonstrate the possibilities within the Fab Lab for the program (see Appendix M). Students had the option whether they choose to fill the interest form out. The form questions students about their STEM interests, musical interests, and cultural interests and was translated into Spanish. See Appendix N for the full form we sent out. We analyzed the data from this form to determine the most inclusive and engaging educational program for our demographic. The data was stored in an Excel sheet. Due to the multiple-choice format of our questions we grouped the data to make charts and graphs. While we will not be present to see the program implemented, we developed a post-program questionnaire (Appendix O) for the students who participate in the program to complete so that future teams can assess whether our goal for the program was fulfilled.

1.4 Proposed Timeline

The Gantt chart in Figure 6 displays the projected timeline. The first two weeks in Spain required us to conduct a field assessment of the University's Fab Lab. From there we were able to order our materials and begin designing our instruments. We also took the time to learn how to use the machines in the Fab Lab machine and began to conduct interviews with professors, students, and cultural experts in Cádiz. Due to Semana Santa, week 3 heavily focused on the construction of our education program where we created the general day-to-day lesson plans. Once the extra materials arrived, we began prototyping in Week 4. We completed our prototyping by week 5 which allowed us to finalize the educational program, refine our prototypes, and run a workshop in the last two weeks.

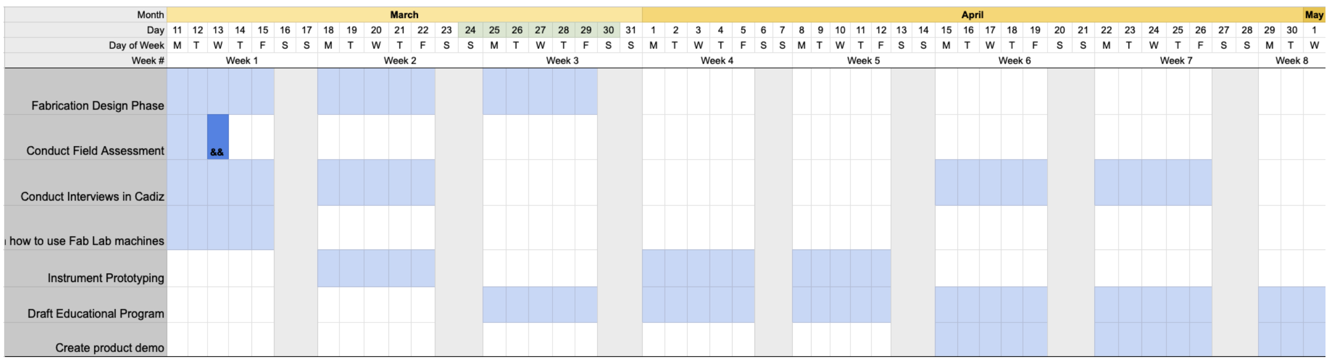


Figure 6: Gantt Chart for Research Timeline (see also Methods Timeline)

Results and Analysis of Fabrication Techniques

After identifying and experimenting with suitable Flamenco musical instrument design in the Fab Lab, the team was able to successfully develop playable castanets and cajónes. We attended Flamenco shows to analyze the rhythms and harmonics of authentic instruments (see Figure 7). By closely studying the instruments during the performance, we gained valuable insight into the construction and sound production. From this experience we were able to leverage the technologies of the Fab Lab to recreate the traditional instruments. Moreover, by experimenting with different materials and designs in the fabrication lab, we were able to develop Flamenco instruments with an appreciation for their cultural origins.

Figure 7: Flamenco show at Peña Flamenco la Perla de Cádiz

We came into the Fab Lab with a plan to make a wooden cajón as our background research informed us of the importance of the wood for the acoustics and resonance of the instrument. For our castanet, we planned to do a 3D printed castanet since our background research informed us that the shape and structure are the most crucial aspects of the acoustics on the instrument. We showed Ana Pilar our initial design plans and after our interview and discussion, we developed our field of action for fabrication. While we did this field assessment, we learned how to utilize the technologies in the Fab Lab. We asked her about possible methods to cut wood as well as integrate Flamenco inspiration into the design process. After completing a laser-cutting workshop with her, she taught us how to use the system, InkScape, to cut the wood as well as engrave it. We decided that we would use the machine to cut our pieces, specifically the top, bottom, and back hole. We also decided that engraving will be a unique way for students to customize their instruments.

Castanet Fabrication

We shifted our initial plans for the castanet to expand our use of tools within the Fab Lab. During our first week, we learned how to work with resin and molding and we considered using that to make our castanet. We asked Ana about some possible materials we could use to make the negative mold for it in order to replicate the authentic shape of a castanet. She suggested using silicone to develop the negative around a real castanet which could then be casted into a resin one. Another suggestion she gave us was using the wax printer to develop it. With limited materials and time we decided to work with the silicone and resin.

We also hoped to 3D print a carnival flute because of its cultural relevance during the time we were here in Cádiz. A major limitation to the construction of instruments was the time constraint and machine maintenance. The carnival flute was unable to be completed due to the machine maintenance required on the 3D printer. Despite these limitations, we were able to complete the cajón and castanets and refine the cajón prototype with a second version. Due to shipping errors with the silicone and resin, we were unable to remake the negative mold but we troubleshooted ways to improve our original process. A prominent part of the engineering process is trial and error. After our first round of trials, we learned which materials we needed more of and what we would do differently in our second round of trials.

The first prototype we made was the castanets (see Figure 8). We began by building a wooden box that was to be used to pour our silicone mold. We used a real castanet, held up by string, to develop the negative. Once the silicone was set, we cut the mold in half to remove the castanet. The mold was taped into place and a hole was carved out of the top to pour the resin into the mold. The resin has to sit for approximately 24 hours before it sets entirely. Once the first castanet was completed, the second one was poured. After we had a working pair, they were tied together with string to finalize the instrument. See Appendix P for the full procedure for building a castanet. There were a few things that we discussed with Ana that we would do differently when re-molding the silicone negative. First, due to the time it takes for the resin to dry, we would make a mold that can hold the castanet pairing so that each piece does not need to be made individually. Secondly, we would measure out the ideal size of the box rather than using the readily available wood. This would allow us to create more than one mold using excess silicone. Third, it is important to ensure that the castanet stays straight within the wooden box. Our mold got tilted which made cutting the mold more difficult. Nevertheless, the castanet came out playable, but it would have made the resin-pouring process easier.

Figure 8: Castanet Prototypes

Cajón Fabrication

The second prototype we made was the cajón (see Figure 9). We used the laser cutter to cut the dimensions as well as the acoustic hole for the back panel. We also utilized the engraving capabilities of the laser cutter to customize our top panel. The drum was completed over 3 days to the time needed for the wood glue to dry as well as the limit of clamps accessible to us. We used wire and excess wood to create the snare effect on our cajón. Once the entire cajón was constructed, we put the wood finish on top to prevent degradation. See Appendix Q for the full procedure for building a cajón. We learned a few important tips from our experimentation with our first cajón. First, the laser cutter does take off a bit of excess wood so that is important to account for when sizing the cajón. It is also important to use the laser cutter at 100% when cutting through wood that is 1cm thick. The team found that running the laser cutter twice over the same section is also helpful when it comes to cutting the wood fully without having to force it to break. Second, having excess clamps is crucial to maintain the integrity of the cajón shape. This was an example of how working with materials available rather than what is required can be beneficial. While we did not have as many clamps as we would have liked, we were able to use string to create tension around the cajón to hold its shape together. We also used heavy objects around the room when we needed extra supplements for clamps.

The team had enough time to make another cajón and implement the changes, allowing for a much smoother fabrication process. We attempted to use the CNC machine in the lab rather than the laser cutter to see if that would produce more reliable lengths of pieces but it ended up damaging the wood. We stuck with laser cutting each piece twice which did prove helpful this round. The next change we made was gluing and then immediately nailing the top and bottom panels to the side panels. This ensured that the cajón did not curve outwards as it had originally done. This allowed us to maximize the amount of clamps we used when piecing the cajón together. The final change we made was the decision to glue the back panel on rather than nailing it. By both gluing and nailing the top and bottom pieces, the cajón was very structurally sound so we felt that glue was sufficient. See Figure 9 to see the comparison between the first and second prototype. We updated Appendix Q as necessary with the changes from the second trial.

Figure 9: Cajón Prototypes

Professor Scott Barton, of WPI Humanities and Arts Department, teaches the course Making Music With Machines and provided us with fundamental insight into how we approached both our prototyping and program. We first asked, “What types of projects have students undertaken in the course, and how did they integrate technology and music?” Professor Barton shared that students typically take 3-4 weeks to gain the foundations and a key component is to keep the vision trackable by beginning with simpler tasks and easing into the more difficult ones. In our program, we utilized this by starting the beginning classes with the basics such as safety, intro to laser cutting, and how resin sets. We also asked Professor Barton “Can you share any insights into the challenges and successes students face when creating music with machines?” He answered that an exploratory approach is typically the best approach. It is important to understand why sound works the way it does and why certain materials work better than others. He informed us that some good materials include: 80/20 aluminum for structures because it is easy to work with and cut, styrofoam, and prototyping with wood. It is also good to consider what can be obtained at hardware stores. We used this information to develop our prototyping by finding accessible materials at a hardware store in Cádiz. This included the wood for our cajón, a hammer, wood clamps, wire, and string. We obtained silicone and resin from Amazon which is also easily accessible.

We also discussed important questions specific to collaboration and teaching. We asked, “What role does collaboration play in your course, especially in the context of instrument design and fabrication?” He informed us that the most important thing is to know what the students know from the start. In terms of groups, there are two ways to approach this: self-organized groups or strategic groups. Strategic groups are valuable because the instructor can create teams with individuals who may have prior experience with those that have no experience. Lastly, we asked, “Are there any specific strategies or resources you find particularly effective in teaching this course?” Professor Barton gave us a very valuable resource called “Musical Instrument Design” by Bart Hopkin which has basic information on making musical instruments and effectively teaching it. Overall, our interview with Professor Barton helped us plan out our program and learn about valuable teaching techniques.

At the Museo de Cádiz, we were able to learn more about Andalusia’s diverse culture through artifacts, artworks, and historical narratives. The team gained a better understanding of the socio-cultural influences that have shaped Andalusian identity, including its Moorish, Jewish, and Christian heritage. At the Reina Sofia Cultural Center, we talked with a Flamenco expert, Francisco Perujo Serrano, about our project and goals as well as the current state of musical education in Spain. Similar to what our background research informed us, we learned Flamenco and its history is not taught as a primary part of education in comparison to subjects in STEM. Thus, we made sure to include historical and musical integrations in each lesson of our program using knowledge we learned from background research, observation at Flamenco shows, and findings from the Museo de Cádiz.

Figures 10 and 11: Museo de Cádiz (left); Reina Sofía Cultural Center (right)

As we developed our prototypes, we began developing our procedures for the instruments. Per our design work and interviews, we developed an educational program centered around the construction of castanets and a cajón with both cultural content and STEM integration. See Appendix S for our entire program outline. In the last two weeks of our fieldwork, we had the opportunity to do a small trial run of one day out of our lesson plan. We worked with a group of six high school students from the region to teach them about laser cutting and the use of other technologies. The students were able to pick a design to engrave in wood and learned how to vectorize it on a computer software. During this process we observed the students to have a high level of interest in the fabrication process by providing the ability to customize aspects of their design and engraving parameters. We also conducted a short survey regarding their backgrounds and possible interest in such a program as the one we are developing. The results of this can be seen in Figure 14. Based on our results, we were able to conclude that there was a general interest in pursuing such a program. Students were most interested in the fabrication of carnival flutes, then the cajón, then the castanets. We suspect that this order of interest is due to some students preferring other genres of music over Flamenco as well as not having a musical background.


Figures 12 and 13: Laser Cutting Workshop at the University

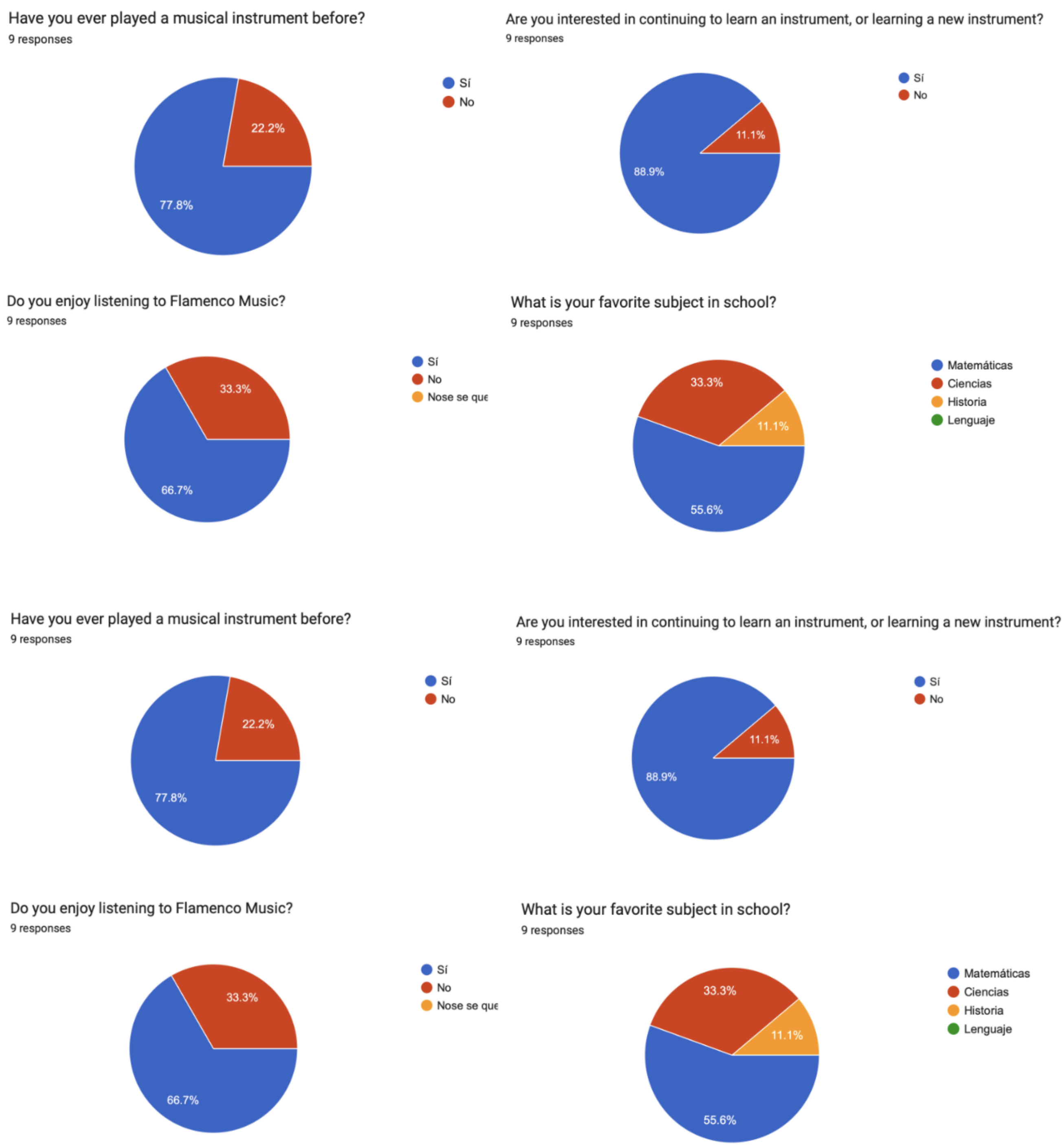


Figure 14: Results from Survey

Conclusions & Recommendations

During our fieldwork at the Fab Lab at the University of Cádiz, we successfully prototyped a wooden cajón and castanets made out of resin. During our fabrication we overcame many hurdles and received constructive feedback from UCA students and professors. Thanks to this trial and error approach we were able to build structurally authentic and resonant instruments. Furthermore, we developed an educational program based on our approaches and procedure, observations of Flamenco culture, and interviews with engineering professors and students. Through this project we learned the importance of collaboration and time management. Keeping an open and creative mind was also an essential step in our fabrication process. When constructing our first cajón we leveraged problem solving skills when we did not have enough clamps to hold the wood panels together. We decided to utilize unconventional materials such as strings to hold the cajón in place while the wood glue dried.

Our recommendations for educators instructing how to build instruments using Fab Lab technology is outlined in Appendix S. We have also included our recommended procedures for a resin castanet (Appendix P) and a wooden cajón (Appendix R). An important aspect of note for the fabrication techniques and design process is the importance of problem solving. We ran into limitations based on machine maintenance and limited access to materials. Brainstorming effective substitutions with students is vital for the success of the program when things go wrong. In our program we have outlined possibly troubleshooting errors and ways which we overcame such obstacles.

Recommendations for Future Fab Lab Teams

For future WPI students continuing this IQP project we suggest setting more time aside than necessary for completing fabrication tasks. From our group's experience in the Fab Lab we have learned that the machines including the Laser Cutter and 3D printer are inconsistent. There were times when the machines malfunctioned and set our time line back. As mentioned in the results the 3D printer in the Fab Lab was out of commission during our seven weeks. Due to this setback we were unable to fabricate one of our main instruments, the carnival flute. Additional advice for future Fab Lab groups is to construct a list of necessary project materials during ID2050 to send to the sponsor to order before arriving in Cádiz. The sponsors have busy schedules so to ease this process, include links and spreadsheets of where to purchase and a cost breakdown. Our team had sent a broad list before arriving and created a more detailed list in Cádiz which delayed our fabrication process. Furthermore, fostering a relationship with students and professors in the Fab Lab and establishing channels for communication is extremely important. The students and professors at the University of Cádiz helped us greatly with learning the machines available in the Fab Lab and navigating setbacks during fabrication. Without establishing these relationships in the first week we would not have been able to accomplish as much as we did. Lastly, we encourage future project teams to maintain a flexible and adapting mindset when approaching their fabrication tasks. Despite planning, unexpected obstacles may arise, requiring problem solving and compromise. For our project we did not have enough time and resources to reach all of our project goals so we had to pick and choose the most feasible and efficient instruments and techniques to execute.

References

Barraclough, T.J., Carnegie, D.A., & Kapur, A. (2015). Musical instrument design process for mobile technology. New Interfaces for Musical Expression.

Blikstein, P., Kabayadondo, Z., Martin, A., & Fields, D. (2017). An Assessment Instrument of Technological Literacies in Makerspaces and Fab Labs. Journal of Engineering Education, 106(1), 149–175. 16 Jan. 2024. https://doi.org/10.1002/jee.20156

Bill. (n.d.). *What is Inside a cajón?* Retrieved February 14, 2024, from https://www.cajónsmadein.com/cajón-construction/what-is-inside-a-cajón.html

Cabedo-Mas, A., & Díaz-Gómez, M. (2016). Music education for the improvement of coexistence in and beyond the classroom: a study based on the consultation experts.Teachers and Teaching, 22, 368 - 386.

Classical and Flamenco Guitar Wood Characteristics. (n.d.). XGuitars. Retrieved February 14, 2024, from https://www.xguitars.com/pages/info

Cuellar-Moreno, M. (2016). Flamenco dance. Characteristics, resources and reflections on its evolution. *Cogent Arts & Humanities*, *3*(1), 1260825. https://doi.org/10.1080/23311983.2016.1260825

Deboick, S. (2023, May 23). *Flamenco, the symbol that can't be tamed*. The New European. https://www.theneweuropean.co.uk/flamenco-the-symbol-that-cant-be-tamed/

Dougherty, D. (2013). The Maker Mindset.

Farrant Dan, (2022 May 24th) *12 Traditional Spanish Musical Instruments* | HelloMusicTheory. (n.d.). Retrieved January 30, 2024 from https://hellomusictheory.com/learn/spanish-instruments/

Flamenco History. (2005). Retrieved January 30, 2024, from http://www.artsflamenco.org/flamenco.html#

Gaur, Aakanksa (2023). *Flamenco | Dance, Music, History, Artists, & Facts | Britannica*. Retrieved January 30, 2024, from https://www.britannica.com/art/flamenco

Guitars, C. (2024). *Classical vs Flamenco | Córdoba Guitars*. Cordoba Guitars. Retrieved February 14, 2024, from https://www.cordobaguitars.com/live-play-learn/differences-classical-flamenco-guitars/

Hagerman, M. S., Cotnam-Kappel, M., Turner, J.-A., & Hughes, J. M. (2022). Literacies in the

Making: Exploring elementary students' digital-physical meaning-making practices while crafting musical instruments from recycled materials. *Technology, Pedagogy and Education*, *31*(1), 63–84. https://doi.org/10.1080/1475939X.2021.1997794

Holguín, S. (2019, October 24) Magazine, S. *The Complicated History of Flamenco in Spain*. Smithsonian Magazine. Retrieved February 1, 2024, from https://www.smithsonianmag.com/travel/complicated-history-flamenco-spain-180973398/

Hopkin, B. (1996). *Musical instrument design : Practical information for instrument making*. See Sharp Press.

How castanets is made - material, making, history, used, parts, steps, History, Raw Materials, Design. (n.d.). Retrieved February 14, 2024, from https://www.madehow.com/Volume-5/Castanets.html

Intro. To Signal Processing:Harmonic analysis. (n.d.). Retrieved February 14, 2024, from https://terpconnect.umd.edu/~toh/spectrum/HarmonicAnalysis.html

JIMÉNEZ. (2023, October 25). *Estos son los 9 proyectos culturales en Cádiz Que Han recibido 16 millones de los fondos ITI*. lavozdelsur.es. https://www.lavozdelsur.es/ediciones/provincia-Cádiz/estos-son-9-proyectos-culturales-Cádiz-recibido-16-millones-fondos-iti_304161_102.html

Jar, D. (2024, January 17). *El Turismo alcanza Una Cifra Histórica: Cierra 2023 con un peso del 12,8% del pib Y 187.000 millones*. La Razón. https://www.larazon.es/economia/turismo-alcanza-cifra-historica-cierra-2023-peso-128-pib-187000-millones_2024011765a7fb18014c8a0001ce61c4.html

José Luis Aróstegui (2016) Exploring the global decline of music education, Arts Education Policy Review, 117:2, 96-103, DOI: 10.1080/10632913.2015.1007406

KATIE. (2024, February 7). *What Is A Castanets In Musical Instrument*. https://brightstarmusical.com/what-is-a-castanets-in-musical-instrument-2/

Kohtala, Cindy & Bosqué, Camille. 2014. The Story of MIT-Fablab Norway: Community Embedding of Peer Production. Journal of Peer Production. Issue 5. 8. ISSN 2213-5316 (electronic).

Kontogeorgakopoulos, A., & Kotsifa, O. (2019). *Game|Lan: Co-designing and Co-creating an Orchestra of Digital Musical Instruments Within the Fab Lab Network*. Linux Audio

Conference (LAC-19). https://alexandros-k.com/media/LAC2019.pdf

Ludwigsen, D. (2015). *Acoustic and structural resonances of the cajón*. 035005. https://doi.org/10.1121/2.0000516

MacCarthy, H. (n.d.). Zarzuela. *Encyclopædia Britannica*. Retrieved February 1, 2024, from https://www.britannica.com/art/zarzuela

Ortega Albaladejo, J. F. (2020). "Vamos por alegrías", for recorder and instrumental Orff: A didactic proposal for an approach to flamenco. Revista de Investigación sobre Flamenco "La madrugá", (17). https://doi.org/10.6018/flamenco.456311

Othman, A., Ahmed, S., & Al-Mohannadi, A. D. (2022). *Madafablab: An inclusive STEM and fabrication environment for ...* MadaFab Lab: an inclusive STEM and fabrication environment for creativity and innovation and its impact on persons with disabilities . https://nafath.mada.org.qa/wp-content/uploads/2022/10/MadaFab Lab-an-inclusive-STEM-and-fabrication-environment-for-creativity-and-innovation-and-its-impact-on-persons-with-disabil.pdf

Remnant, M. (1990). Musical Instruments: An Illustrated History from Antiquity to the Present.

Romero, Angel (2021, September 30). *All About Flamenco | World Music Central*. https://worldmusiccentral.org/2021/09/30/all-about-flamenco/

Rumpala, Y. (2014). Fab labs and makerspaces: Between innovation and liberation? *Revue Internationale De L'économie Sociale*, *334*, 85. https://doi.org/10.7202/1027278ar

Sar, M.M., Mulder, I.J., Remijn, L., & Troxler, P. (2013). Fablabs in design education. *Spain: Skateboard and soda cans make musical - ProQuest*. (n.d.). Retrieved February 1, 2024, From https://www.proquest.com/docview/2615135585?parentSessionId=gccFqWPDLqGfzvPuElFDDRkuTGIdyMMku6uBnUbzGBg%3D&pq-origsite=primo&sourcetype=Newspapers

Soret, A. (2019, April 5). Children of Spain. Humanium. https://www.humanium.org/en/spain/

Temporalización—Centro Andaluz De Documentación Del Flamenco. (2021). Retrieved January 23, 2024, from https://www.centroandaluzdeflamenco.es/temporalizacion

Team, A. (2018). *cajón Basics | What You Need to Know*. Retrieved February 14, 2024, from https://www.aimm.edu/blog/cajón-basics-what-you-need-to-know

The Best Wood to Use for cajón Drums. (n.d.). Retrieved February 14, 2024, from https://www.cajónsmadein.com/the-best-wood-for-cajón.html

The Editors of Encyclopaedia Britannica. (n.d.). Jota. *Encyclopædia Britannica*. Retrieved February 1, 2024, from https://www.britannica.com/art/jot

The Structure of the Classical Guitar : The flamenco guitar-similar, yet different - Musical Instrument Guide - Yamaha Corporation. (n.d.). Retrieved February 14, 2024, from https://www.yamaha.com/en/musical_instrument_guide/classical_guitar/mechanism/mechanism003.html

Trombeta, G., & Cox, S. M. (2022). The Textual-Visual Thematic Analysis: A Framework to Analyze the
Conjunction and Interaction of Visual and Textual Data. The Qualitative Report, 27(6), 1557-1574.
https://doi.org/10.46743/2160-3715/2022.5456

Togou, M. A., Lorenzo, C., Cornetta, G., & Muntean, G.-M. (2020). Assessing the Effectiveness of Using Fab Lab-Based Learning in Schools on K–12 Students' Attitude Toward STEAM. *IEEE Transactions on Education*, *63*(1), 56–62. https://doi.org/10.1109/TE.2019.2957711

Wilkinson, I. (2023, April 12). *Flamenco defined by law to keep Andalusia in step with history*. The Times & The Sunday Times: breaking news & today's latest headlines. https://www.thetimes.co.uk/article/url-flamenco-defined-spanish-culture-2023-8p5ds0dn9#:~:text=The%20new%20law%20attempts%20to,the%20historical%20influence%20of%20other

Appendix

Appendix A: List of Musical Instruments Created in Spain (Farrant, 2022)

1. cajón: A percussion instrument, often played with your hands. Brought back by the Spanish from South America as they enjoyed it and wanted to incorporate it back home. Now it is an incredibly important instrument in Flamenco and other styles of Spanish music.
2. Laud: A string instrument that uses 12 strings and is often played along the Bandurria, Guitar, and other folk instruments. It is usually performed in a Rondalla which is a Spanish Folk musical group.
3. Castanets: A traditional Spanish percussionist instrument often made from ivory or hardwood. And these are utilized by Flamenco dancers as they are worn on your fingers.
4. Bandurria: A String instrument, and a type of lute that is widely heard in Spanish and Latin American music.
5. Vihuela: A String instrument that originated in Spain that can have up to 12 strings. The instrument resembles a smaller Guitar at around 3ft long.
6. Gaita Gasterona: A hornpipe that originated in the Andalusian region called El Gastor. Typically played by younger people during the months leading to Christmas (November and December).

Appendix B: More Details on the History of Flamenco

Origin of Flamenco

Many details about the origin of Flamenco are lost in history for a variety of reasons. The pioneers of Flamenco were persecuted during the Spanish Inquisition resulting in a slower rise in the popularity of Flamenco. By the time Flamenco was popular in Spain, questions of its origins arose. Flamenco was inspired by the Roma population who assimilated in Seville and Cádiz. There was a dynamic culture of Arabs, Christians, Berbers, Romas, and Jews while the "Moorish" dynasties ruled southern Spain in the 1400s. The Moorish style of singing expressed the difficulties of being outcasts in Andalusia and sang of despair but also hope. The Spanish Inquisition forced this dynamic culture of individuals out beginning in the late 1400s through the early 1800s (*"Flamenco",* 2005; Manuel, 1986). Romas follow oral tradition so the folk songs of Flamenco were passed down orally from generation to generation. This made it harder for Flamenco to stick while groups were pushed out and executed. Flamenco was also not considered a form of art to those in Spain for a long period as a result of the low opinion of the assimilated groups; it was not recognized in Spain until its golden age in the late 1800s. During this golden age, music cafes called "cafes cantantes' became very common. These cafes generated a lot of attraction from the music, the dancers, and the guitars. From there, Flamenco was born in Spain, despite its true origins a few centuries before (*"Flamenco",* 2005).

After its golden age, Flamenco received backlash from Spain elitists in the 19th and 20th centuries. The dance style was considered "vulgar and pornographic" (Holguín 2019) and wasn't something that some natives in Spain wanted tied to their country. It was also seen as a threat by the Catholic Church. The church believed that Flamenco promoted immodesty, and feared it threatened their teachings. Intellectuals saw it as a hindrance to finding solutions to structural, real problems in Spain. They believed it kept locals and commoners from worrying about the condition of their living; a distraction. After the Spanish Civil War, there wasn't much talk of Flamenco until Francisco Franco utilized Flamenco to draw in tourism. This led to the popularization of Flamenco as a business opportunity.

By the 1970s and 1980s, Flamenco began to pick up internationally. While Flamenco is more traditional in its styles, waves of bands hoped to bring new, younger audiences to the arts by fusing other forms of music like salsa, blues, jazz, rock, and even pop with it. In Southern Spain, many tourists travel to see and hear Flamenco (Romero, 2021). Tourism is one of the major sources of income for Spain and contributes more than 12% of Spain's GDP. Due to Spain's strict closure of its borders during the pandemic, a lot of Spain's tourism sector suffered a devastating hit putting most on the brink of closing while other local cultural establishments had to close. This includes many local artists who have lost their livelihoods to the pandemic. While the fusion forms of Flamenco are popular internationally, there was a recent surge in the desire to learn about Flamenco's origin in southern Spain. This has especially helped the region's local music industries and economy post-COVID. Many tourists travel annually to see and learn about the origins of Flamenco. More recently, Flamenco schools have also opened to teach Flamenco to the international clientele, reviving the economy further (Aoyama, 2021; Romero, 2021). Now just in 2023, they saw an increase of two million tourists setting a historical record high of 85 million tourists in one year bringing more than 187 billion euros into the country. The government is expecting this prosperity to carry over to 2024 and started to take action to ensure its success. (Jar, 2024)

Governmental Intervention on Behalf of Flamenco

The Spanish government has taken steps to preserve the Flamenco culture in the Andalucia region. The Andalucia parliament passed the Flamenco law which defines Flamenco's roots in Roma populations and enforces that schools in the Andalusian region incorporate Flamenco in their curriculums. Many local musicians have spoken up about the lack of funding from part of the government for Flamenco music. For this reason, Arturo Bernal, the one in charge of the legislation, states that funding will come with this new proposed law. Another hope is that this law would help rejuvenate Flamenco music like the Concurso del Cante Jondo, a competition held in Granada where it helped keep the culture afloat when it was at risk of dying out. "The law establishes a legal framework for flamenco for its protection, conservation, and the promotion of knowledge about it, ensuring its transmission to future generations," Arturo Bernal says (Deboick, 2023).

In the region of Cádiz, there are also several new cultural projects coming to fruition such as the new "Museo de Andaluz del Flamenco" which will help the region gain more tourism traction while at the same time preserving the culture of Flamenco by putting it on display for the world. This is not the only project coming to the public, as they are also proposing dedicated centers for the iconic musicians Camarón de la Isla, the most recognized flamenco singer in history, and Paco de Lucía, the best flamenco guitarist in history. This is a direct result of the regional government of Andalucia investing a total of 16 million euros into this initiative co-financed by the Federal Funds for Integrated Territorial Investment (ITI) (Jiménez, 2023).

Other Music in Spain

While Flamenco is incredibly popular in Spain, Spain is home to many musical styles. Copla is another well-known genre of music found in the Andalusian region of Spain. Although debated, Copla was established in the early 19th century, whereas Flamenco appears in the latter half. Copla is a type of song; sometimes songs that are used in Flamenco could fall under the genre Copla. The primary difference is that Copla has more orchestral influences. It was incredibly popularized throughout the 1940s and 60s. Over the years though, Copla's popularity and demand diminished due to its correlation with Franco's reign in Spain (*"Andalusian"*).

Spanish music styles typically incorporate one another in styles. Fandango, a courtship dance and a genre of Spanish folk music, consists of Copla melodies. This genre came from Moorish origin and remained incredibly popular throughout most of Spain and some southern regions of France. Fandango is a passionate and flirtatious dance very similar to Jota (Gaur 2023). Jota is a traditional fast-paced dance that originated from the Aragon region, in northern Spain. The dance is accompanied by castanets and the guitar and often involves singing. The songs are often Coplas. Legend claims that this style of dance and song was brought to Aragon by the exiled Moorish poet Aben Jot.

Music in Spain changes as we move from the various cities. Zarazuela is often referred to as the Spanish Opera and is closely related to traditional Madrid. It often goes back and forth between singing and speech. These performances often include solo performances called romanzas. Zarazuela originated in the mid-17th century during King Philip IV's reign. They were first held in a royal hunting lodge called La Zarzuela, which is where the name originated from. These were considered royal entertainment and were incredibly popular during this century. However, shortly after the popularization of French and Italian Opera, the royals traded their local theater for foreign renditions. Zarazuela returned in the 19th century, as plays started to be reenacted in Spanish. This eventually led to the opening of the Theatro de la Zarzuela (MacCarthy).

Appendix C: Results from a Project-Based Learning Study

Table 2 Learning satisfaction of Shubailan online learning in an online flipped classroom approach

Statements	Mean (n = 122)
1. I have a more flexible learning mode that I can learn at my own pace as the videos are available at all times online.	3.16
2. It allows me to take time on reviewing the material without lagging behind.	3.19
3. I get less frustrated towards the musical instrument application and music making during the online face-to-face lessons.	3.16
4. I am interested and capable of exploring Shubailan in a deeper manner during the lessons.	3.18
5. The demonstrations and knowledge delivery in the recorded videos give me a better understanding of the Shubailan concepts.	3.30
6. It is more interesting than the traditional face-to-face classroom music learning.	3.13
7. It creates a dynamic, engaging and interactive classroom which focuses on student interactions and music creation.	3.35
8. It allows me to watch the instrumental videos several times.	3.21

(NG et al 2022)

Appendix D: List of Technology Commonly Found in Fab Labs

1. 3D printer: A device that creates three-dimensional objects from scratch using a process called additive manufacturing. It adds layered materials according to a computer model to produce the three-dimensional items.
2. CNC machines: A machine that uses computerized controls to accurately execute machining operations on a variety of materials.
3. Laser cutters: Precision machining tools that utilize a focused laser beam to cut, engrave, or etch materials including metals, plastics, wood, fabrics, and more, with high accuracy and detail.
4. High-resolution milling machines: Advanced machining tools capable of producing finely detailed and precise components, used for printed circuit board milling.
5. Microprocessors: It's a small integrated circuit that serves as a computer or electrical device's central processing unit(CPU). It can perform mathematical and logical operations to carry out a variety of activities by processing and executing instructions that are stored in memory.

Appendix E: Informed Consent Form

Participation Form and Statement of Rights

We are students at Worcester Polytechnic Institute in Worcester, Massachusetts. We are conducting a research project on behalf of the University of Cádiz to design an educational program for young students that integrates STEM with music by building an instrument inspired by Flamenco in the Fab Lab at the University of Cádiz. As part of this project, we are conducting a series of interviews to help us gain a better understanding of the construction of Flamenco instruments. We have asked you to participate because we believe you have unique knowledge for this that will be valuable to the project.

Before we begin, we would like to thank you for taking the time to participate in the interview which will last about 20-30 minutes. Your participation is entirely voluntary. You may refuse to discuss any question or terminate the interview at any time. With your permission, we would like to record the interview. The tapes, notes, and subsequent transcripts of the interview will be kept confidential and will be accessible to only the members of the team and our immediate faculty advisors. Your name will not be used in any subsequent report or publication without your permission.

If you consent to be interviewed at this time, we would ask that you indicate your agreement below.

I agree to participate in the interview

Interviewee Name ________________________________

Interviewee Signature _____________________________ Date____________

Please initial for permission to record ______________

For further questions please contact: gr-Cádiz_24_fablab@wpi.edu

Appendix F: Interview Questions for Ana Pilar

1. What would you recommend when it comes to making a negative mold?
2. To cut wood, what would be some options in the lab?
3. What is the best way to set up our casenet for the silicone mold?
4. What ratios are ideal for mixing the silicone and the resin?
5. How long should we let the resin rest before taking it out?
6. What is the best way to cut the silicone mold to ensure it remains usable?
7. What settings would be best for the laser cutting when engraving vs cutting?
8. How does the 3d printer work? How long does it take to print?
9. How can we make students incorporate color/ personalize their castanets?

Appendix G: Interview Questions for UCA students

What previous experiences have you had using machinery and fabrication techniques inside an environment like a Fab Lab?

Have you ever had to use the machinery inside the Fab Lab to help you finalize a project, be it for school or a personal project? If yes, can you tell us about your experience?

How comfortable are you with the machines in the Fab Lab?

Have you had any formal training or instruction for the machinery?

What challenges or obstacles have you encountered in previous fabrication projects, and how did you overcome them?

Do you have a fabrication technique that you excel in?

Do you have any recommended techniques that you think could be beneficial for the fabrication of musical instruments?

Do you believe that having access to a Fab Lab has helped your learning as a University student? Would you recommend that universities prioritize having a Fab Lab for their students?

Appendix H: Machinery and Materials List

Machines Located at the University of Cádiz Fab Lab

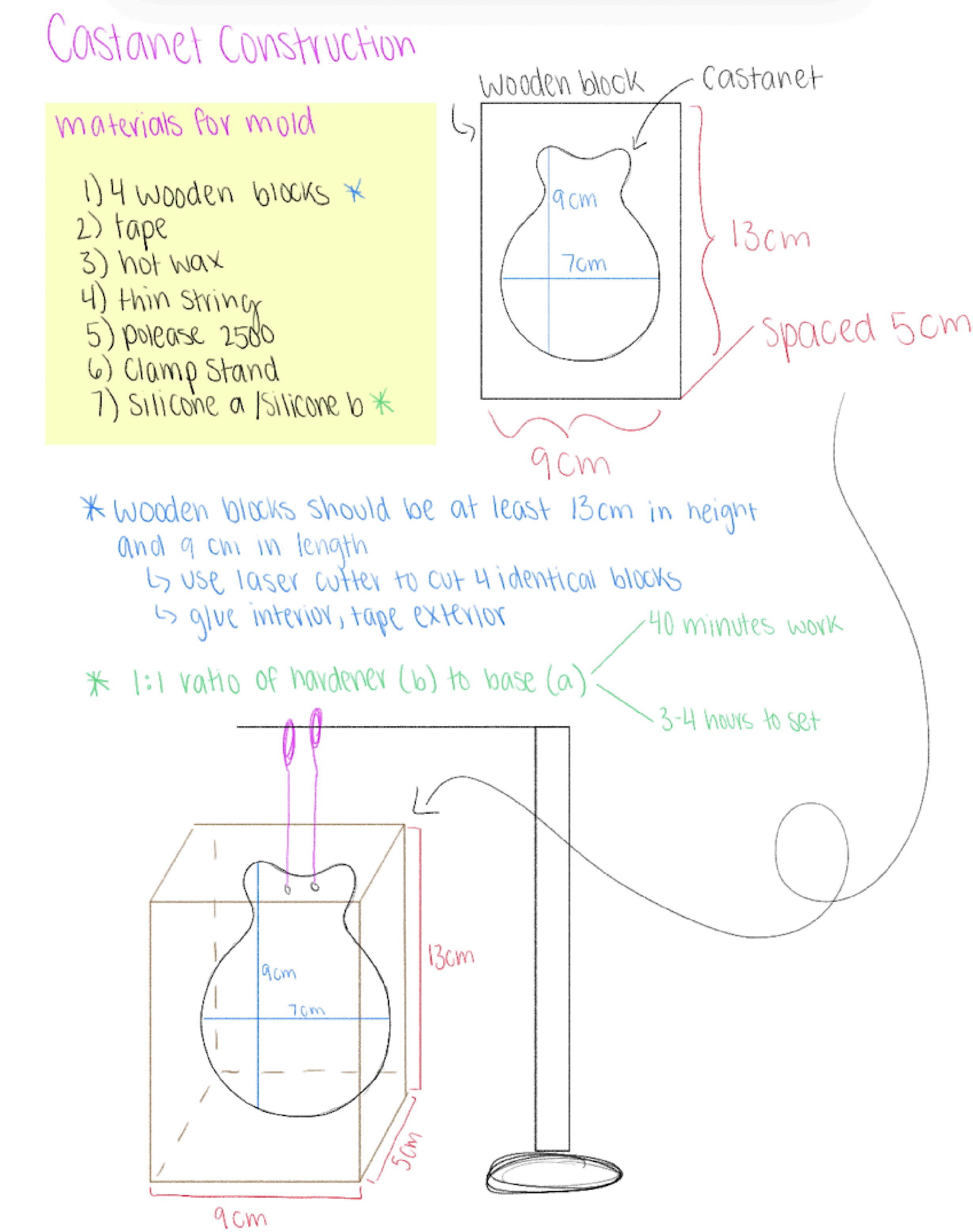
1. Epilog Laser - Fusion Edge 24 - 40W
2. Roland DG - MonoFab SRM-20
3. Roland DG - CAMM-1 GS-24
4. CNC Bárcenas - SW1325V
5. Formlabs - Form 3
6. Formlabs - Form Wash
7. Formlabs - Form Cure
8. Bambu Lab - X1 Carbon
9. Modix - Big-60
10. Rat Rig - V-Core 3
11. Creality - CR-10 V3
12. Creality - Ender 3 (modified to paste 3D printer)

Materials Required for Fabrication (1 castanet, 1 cajón)

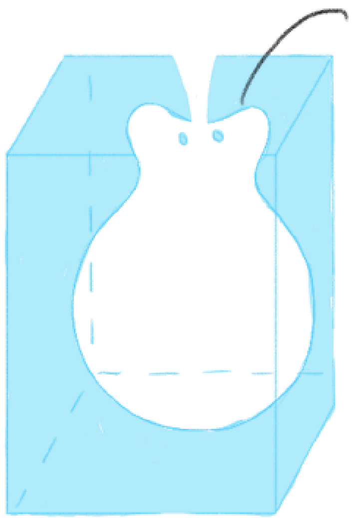
** multiply quantity desired of bolded materials to make more than one

1. **4 wood blocks 5 cm by 9 cm**
2. **2 hot wax stick**
3. Pol-Ease 2500 Release Agent
4. String
5. Ring Clamp
6. Silicone A
7. Silicone B
8. 2 Pouring Vessels
9. Resin A
10. Resin B
11. **6 wood blocks 30 cm x 50 cm**
12. Wood glue
13. SARGENTO AUTOMÁTICO 300MM DEXTER
14. 2 sets of 4 PINZAS SUJECCION 100MM DEXTER
15. Wood Varnish

Appendix I: Design Sketches for Castanet and cajón



Cut the negative mold in half and create a hole at the top to fill w/ resin



the negative mold:

Approximately:

- 48 g sil A
- 30 g sil B

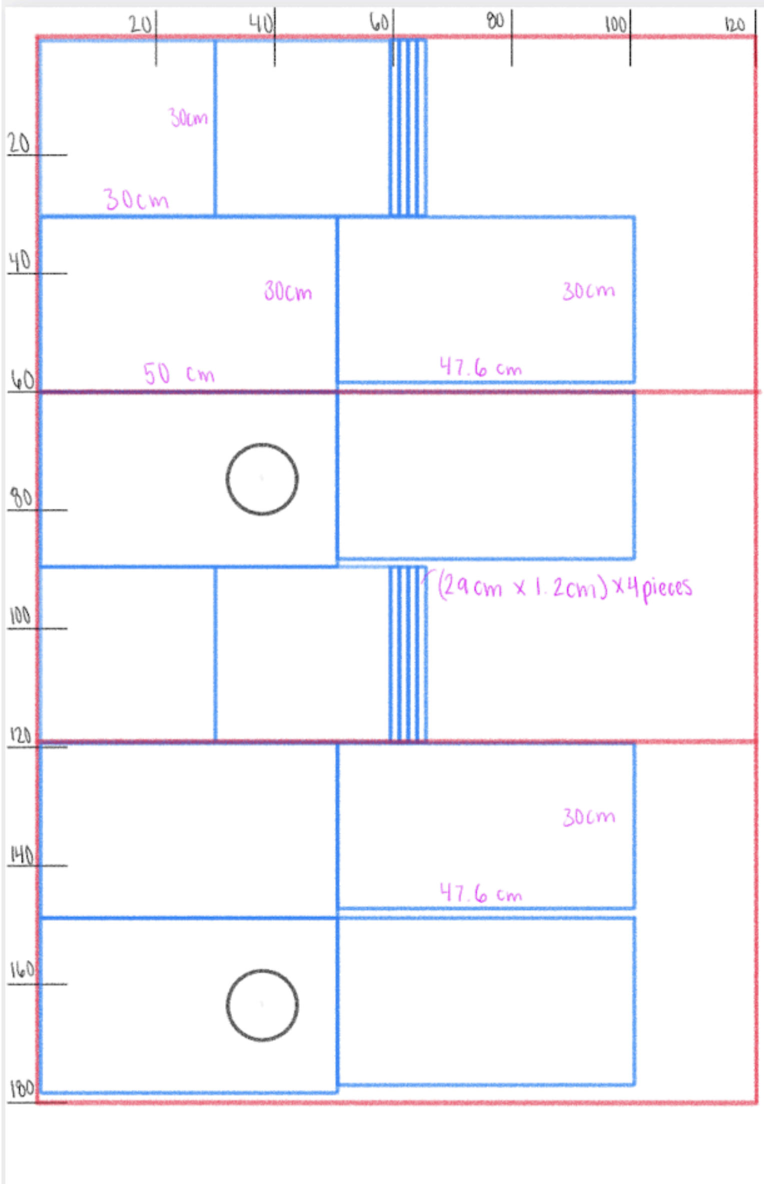
B = 0.6A for any resin mold

tips for pouring the resin:

↳ use a plastic funnel

↳ tape the mold together to prevent leakage

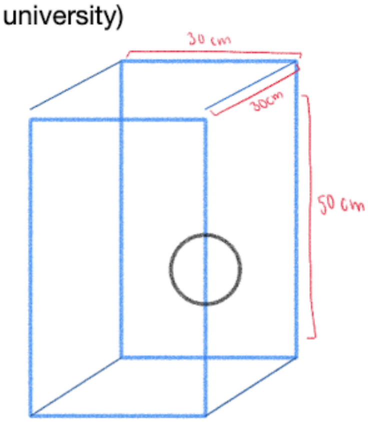
*repeat twice for a castanet set!



If the place can cut it it we'd need 6 blocks of wood that are 30 cm by 50 cm by 1 cm (h x w x t) for one wooden cajon.

For trial and error, 12 blocks of wood that are 30 cm by 50 cm would be ideal.

- 2 panels that are 30 cm by 47.6 cm
- 2 panels that are 30 cm by 50 cm
- 2 panels that are 30 cm by 30 cm
- 4 panels that are 29 cm by 1.2 cm (we can laser cut this at the university)



Step 1: Cut the wooden blocks

- 5 pieces of wood that are 30 x 50 x 1 cm
- 1 piece that is 30 x 50 x 0.5 cm

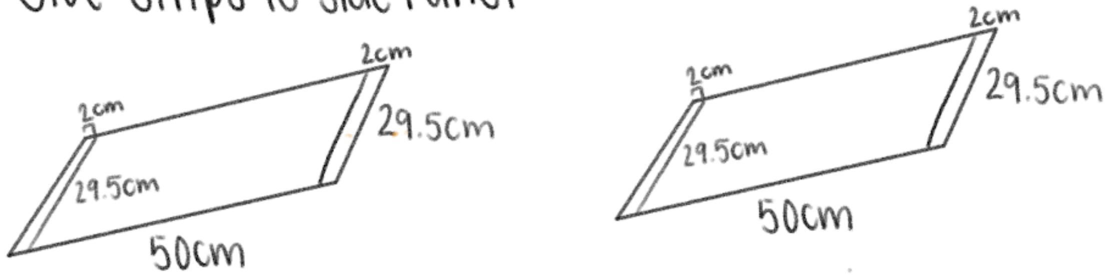
↳ Use laser cutter to make

- 2 30x30x1 pieces
- 1 30x47x1 piece w/ 12 cm circular cutout
- 1 30x47x1 piece
- 4 30x1.2x1 pieces (use leftover from cuts)

Step 2: Assembly

- glue the side pieces (30x1.2x1) to the 2 30x50x1 pieces (use the clamp) -> nail once dry
- bottom front is glued while back/top front are hammered (to insert snares, vibrate)

Glue Strips to Side Panel

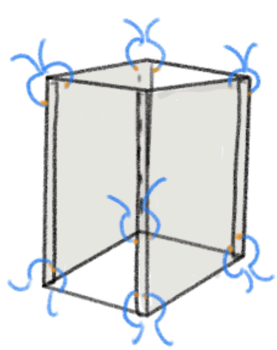


dry for 24 hours
end of Day 1

Glue sides, top, and bottom

Requirements:

- wood glue
- 2 29.5 cm x 29.5 cm panels
- 2 50cm x 29.5cm panels w/ 29.5cm x 2cm inserts
- 8 small clamps



Appendix J: Sample of Educational Program Lesson Plan

Daily Lesson Plan

Lesson Title: Fab Lab Safety	Year Group: All	Duration of Class: 90 minutes	Lesson # of #: Lesson 1 of 10
Fab Lab Learning Objective: 1. Safety precautions to take when working with machines 2. Introduction to machines		Cultural Integration Learning Objective: 1. Flamenco instruments and sound acoustics	
Activities and Timeline: 10 minutes: Introduction to the class 20 minutes: Safety Precautions 30 minutes: Machines Overview 15 minutes: Further expectations for the class 15 minutes: Cultural Integration			
Instructor Materials Needed:		Student Materials Needed	
Notes:			
Preparation for Next Class:			

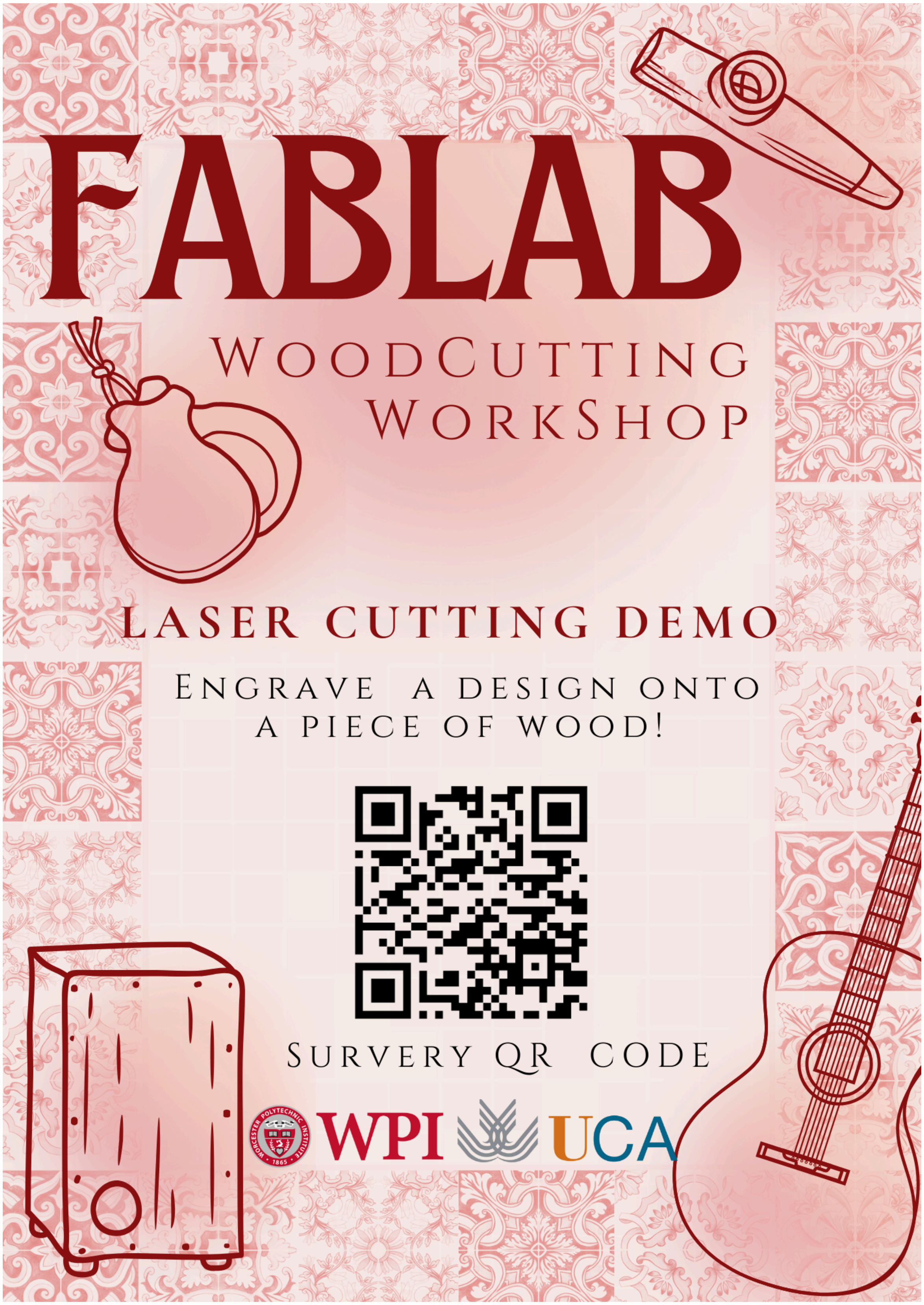
Appendix K: Interview Questions for Scott Barton

1. Can you provide an overview of the course "Making Music With Machines" and its main objectives?
2. What types of projects have students undertaken in the course, and how did they integrate technology and music?
3. What are some of your favorite student projects to date, and why?
4. Can you share any insights into the challenges and successes students face when creating music with machines?
5. How do you structure your course to balance theoretical knowledge with hands-on practical experience?
6. What role does collaboration play in your course, especially in the context of instrument design and fabrication?
7. Are there any specific strategies or resources you find particularly effective in teaching this course?

Appendix L: Interview Questions for Local Cultural Experts

1. How has Andalusian culture influenced the development of flamenco, and what are some key elements that distinguish Andalusian flamenco from other regional variations?
2. How has flamenco evolved in Andalusia, and what role has it played in the cultural identity of the region?
3. What are some iconic venues or gatherings in Andalusia where flamenco performances have historically taken place?
4. How has flamenco been preserved and passed down through generations in Andalusian communities, and what efforts are being made to safeguard its cultural heritage?
5. Can you discuss the relationship between flamenco and other art forms in Andalusia, such as poetry, music, and dance?
6. How has flamenco influenced popular culture beyond Andalusia, both within Spain and internationally?
7. Are there any particular styles or variations of flamenco that are unique to Andalusia, and what distinguishes them from one another
8. What role does flamenco play in contemporary Andalusian society, and how is it being reinterpreted or adapted by modern artists and performers?

Appendix M: Poster for Student Workshop



Appendix N: Interest Form Questions for High School Students

Hello! The Fab Lab Team at Worcester Polytechnic Institute is reaching out to high school students to get your thoughts on our hands-on educational program. We're blending STEM (science, technology, engineering, and math) with music through building instruments in a Fab Lab, and we want to know your level of interest. We're curious about your current interest in STEM and music. Your responses will help us shape our program to make it engaging and enjoyable for you. We're aiming to create a program that excites you and makes learning fun. Our ultimate goal is to spark a passion for both STEM and music that lasts a lifetime. Your answers are confidential and anonymous. We ask that you do not share answers with your peers before or after taking this questionnaire. This survey is all about gathering your insights to make our program the best it can be. If you have any questions please reach out to your school's liaisons (include their information here). Thanks for taking the time to help us!

1. Have you ever played a musical instrument before?

   Yes_____ No______
2. Are you interested in continuing to learn an instrument, or learning a new instrument?

   Yes_____ No______
3. Do you enjoy listening to Flamenco Music?

   Yes_____ No_____ I am not familiar with Flamenco Music ___
4. What is your favorite subject in school?

   Math______ Science _____ History_____ Language_____ Other: ______
5. Would you enjoy participating in a program where you can design and build an instrument?

   Yes_____ No______
6. What instrument below would you be interested in building? (check as many as you'd like)

☐ cajón ☐ Castanets ☐ Guitar ☐ Carnaval Flute

7. Are you planning on pursuing higher education and attending university?

   Yes_____ No______

8. Have you considered going to university to study STEM (Science, Technology, Engineering, Mathematics)

   Yes_____ No______ Maybe _____

Appendix O: Post-Program Completion Survey Questions

1. Did you enjoy this program?

   Yes_____ No______

2. Would you recommend this program to your peers?

   Yes_____ No______

3. Did you feel like this was set at a good pace for you?

   Yes_____ No______

4. Do you feel like you learned something about Flamenco and Andalusian culture?

   Yes_____ No______

5. Do you feel like you learned something about STEM?

   Yes_____ No______

6. Do you think you've built on your current knowledge?

   Yes_____ No______

7. Do you think this program was too long, too short, or just right? Circle one.

   Too short Just Right Too Long

8. How much more inclined are you to pursue STEM? (Circle one; 1 is LEAST inclined and 5 is MOST inclined)

   1 2 3 4 5

Appendix P: Castanuela Fabrication Procedure

Building the Wooden Box

1. Gather all the materials listed above
2. Beginning with a wooden panel, use the laser cutter to cut 4 blocks that are 13 cm in height, 9 cm in width, and 1 cm in thickness. Use the "software procedure" below to complete. (See Laser Cutting Procedure)
3. Space the blocks 5 cm apart and use the hot wax stick on the inside to assemble the box (insert image). Use another wooden panel to build the box on.
4. Tape the box and add more hot wax on the outside of the box.
5. Once secure, add string to the castanet and attach it to the clamp stand, placing it inside the box. The clamp stand should sit approximately 20 cm in height.
6. Make sure that the castanet is not touching any of the sides or bottom of the box (see Figure 15).

Figure 15: Castanet Inside of Wooden Box

Silicone Molding - The Negative

7. Using a 1:1 ratio of Silicone A (base) and Silicone B (hardener), use a scale to measure 250 grams of each.8
8. Mix the solution until it is homogenous. A is dark blue and B is white, so the homogenous mixture should be light blue.9
9. Pour the solution into the wooden box. Repeat steps 1 and 2 as needed until the castanet is fully covered (See Figure 16).

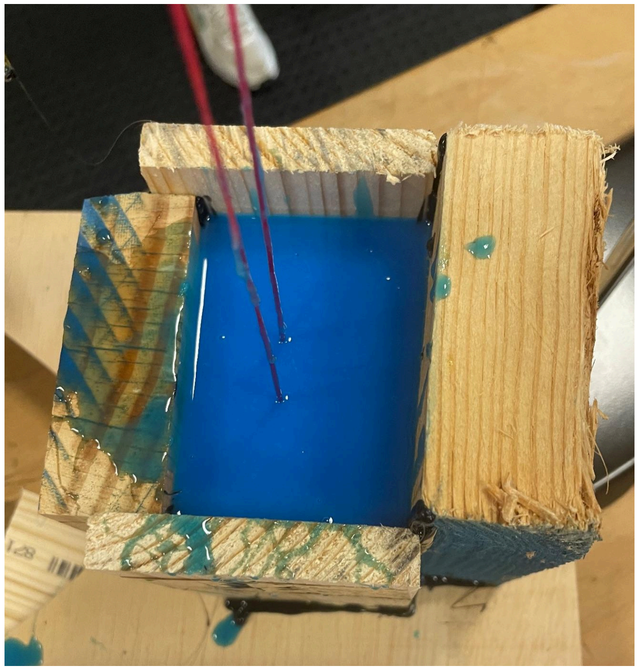


Figure 16: Silicone Mold Poured to Make Castanet

Note: You have 40 minutes to complete the silicone molding step before it begins to fully solidify. The mold should be completely solidified after 4 hours.

Casting the Resin

10. Remove silicone mold from wooden frame
11. Cut the silicone mold in half to remove the castanet
12. Use the box cutter to create a hole which will be used to fill to castanet negative mold
13. Use tape to reseal the mold back together to begin pouring the resin
14. Pour 50 g of resin A and 30 g of resin B into a beaker or cup (10:6 ratio for A and B resin)
15. Use a plastic funnel to pour the resin into the mold
16. Let sit for 24 hours before removing
17. Repeat steps 3-5 again to build the castanet set (See Figure 17)

Figure 17: Resin Mold of Castanet

Final Touches

18. Once both castanet pieces are built, use string to tie them together (See Figure 18).
19. If needed, use sandpaper to smooth the edges

Figure 18: Finished Resin Castanet

Software Procedure Laser Cutting

1. Open Inkscape and start a new page
2. Click on the shape icon on the left-hand bar
3. Draw a rectangle of 9cm by 13 cm

4. Click on File then print and select the Epilog Laser printer then print button again.
5. Epilog Laser software is prompted on the screen
6. Turn On the laser cutter, CO2 machine, and extractor
7. Open the hood, place a piece of wood on the panel, and align the edges up to the ruler.
8. On the computer align the rectangle with the piece of wood using the epilog camera
9. Once the rectangle is positioned go to the right hand side of the screen and select “Cut” next to “Visualizer:”
10. Next select “Probe” in the drop-down menu of “automatic focus”

Appendix Q: Software Procedure on Inkscape

Laser Cutting

1. Open Inkscape start a new page
    a. Click on the square icon on the left hand bar
    b. Draw a 30 cm by 30 cm rectangle
    c. Click on File then print and select the Epilog Laser printer then print button again (see Figure 19).

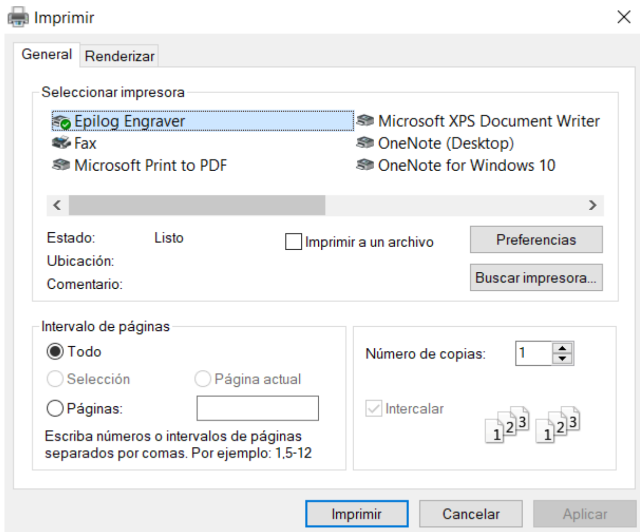


Figure 19: Printer Selection Window

2. Epilog Laser software is prompted on the screen
3. Turn On laser cutter, and the extractors
4. Open the hood and place a piece of wood on the plate and align the edges up to the ruler.
5. On the computer align your rectangle with the piece of wood using the camera
    a. Once the rectangle is positioned go to the right hand side of the screen and select "Cut" next to "visualizer:" (see Figure 20)

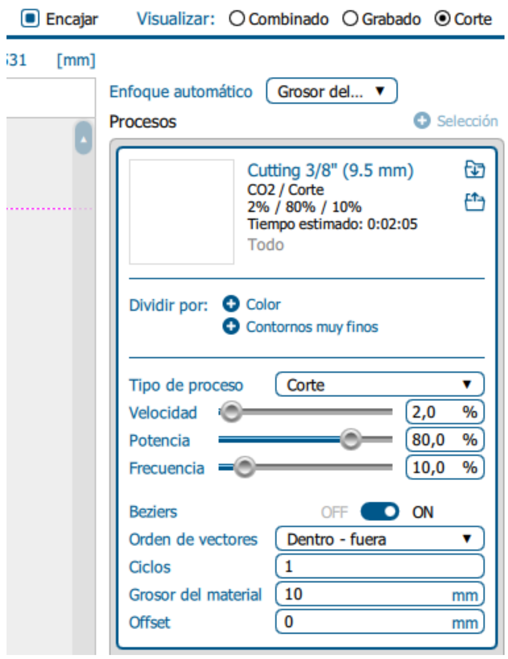


Figure 20: Cutting Parameter Window

b. Select  , on the pop up screen select Cut, scroll down to the bottom of the screen and select “Cutting ⅜ (9.5 mm)”
c. Next select “thickness of material” in the drop down menu of “automatic focus”.
d. In thickness of material box type 10 mm
e. Type 0 mm in the offset box
f. Hit print

6. The file should show up on the laser cutter screen
   a. Select the file and press the play button to run the machine
   b. * make sure the two extractor are running before you press play.

Software Procedure Laser Engraving

1. Open Inkscape and start a new page
   a. Go to files and select import
   b. Select the file you would like to import from the computer (Must be an image file)
   c. Move and size the image to the page
   d. Select the image in the software
   e. Once selected go to the “Trajectory” drop-down from the top toolbar and then click “Vectorize map of bits”, as seen in Figure 21 below.

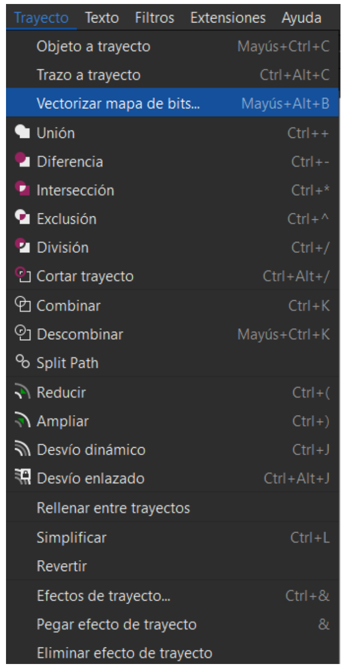


Figure 21: Drop Down Menu for Trajectory

f. On the right-hand side a window will open, select Update Preview at the bottom of the page. As seen in [Figure 22](#) below.

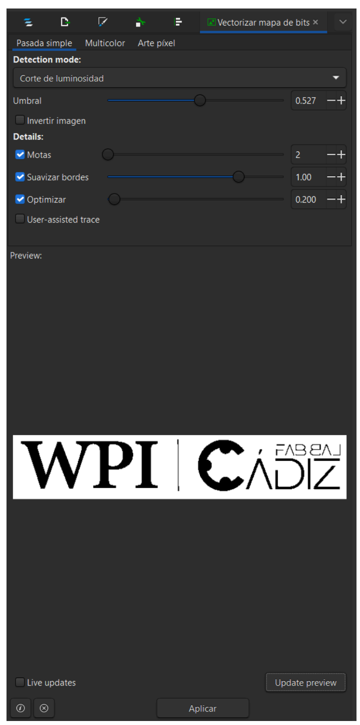


Figure 22: Vectorize Map of Bits Parameter Window

g. The vectorized image will show up in the window.

   h. Play around with the parameters until the image is to your liking, you will mostly see changes from the “umbral” parameter.
   i. Once the image is to your liking click on “Apply” at the bottom of the window, as seen in Figure 22.
   j. On top of the image there should be a new layer with a black & white outline like the one seen in the preview from Figure 22.
   k. Delete the image so that the black & white outline is the only one in the screen, this is the vectorized map of the image you desired.
   l. Click on “File” from the top toolbar then click “print” and select the Epilog Laser printer then print button again, as seen in Figure 23 below.

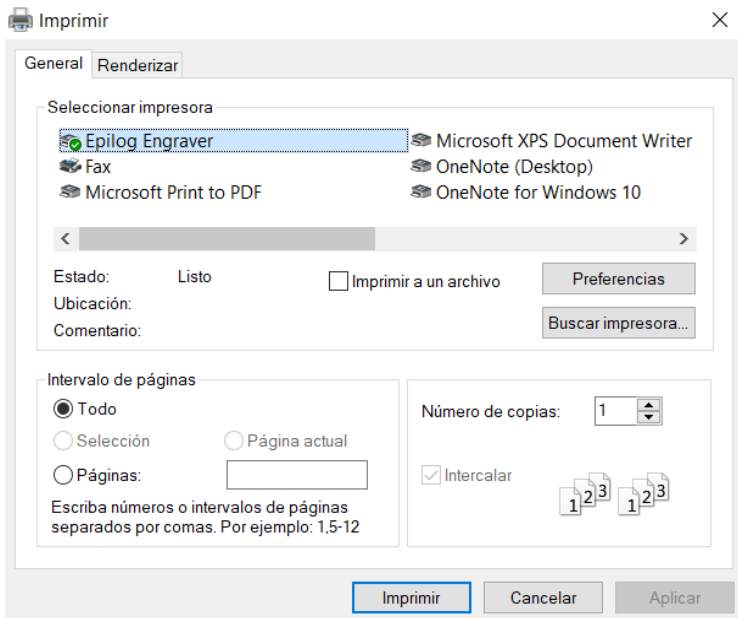


Figure 23: Printer Selection Window

   m. Epilog Laser software will be prompted on the screen
2. Turn On the laser cutter, and the two extractors. (Give sufficient time for the laser cutter to boot up and connect to the software*)
   a. Once you are able to see the laser cutter camera view the laser cutter is connected properly.
   b. Go to the laser cutter and open the hood to place your desired piece of wood on the panel and align the edges up to the ruler.
3. On the computer align the image with the piece of wood using the epilog camera to a desired spot, as seen in Figure 24 below.

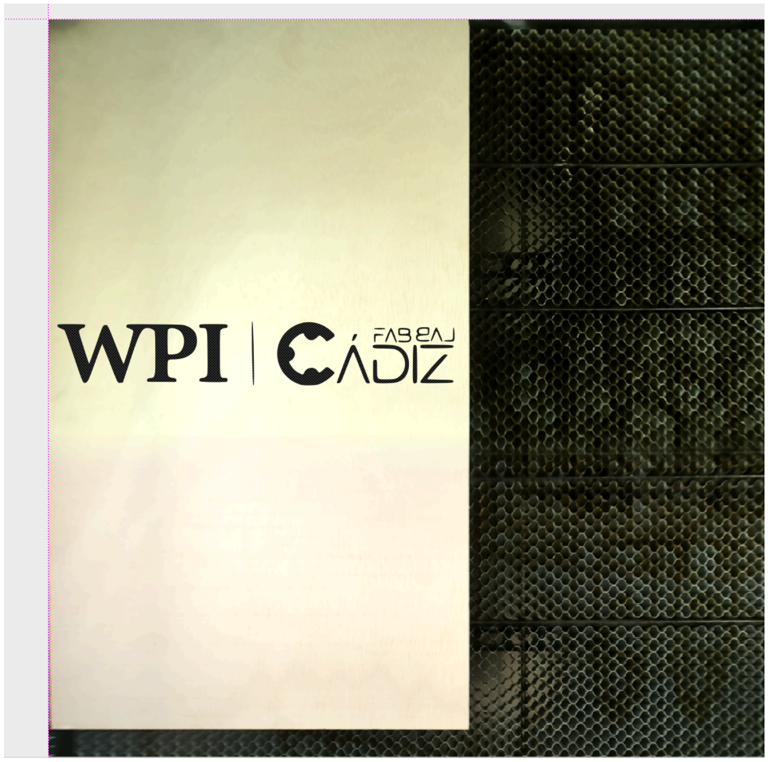


Figure 24: Camara View in Epilogue Software

a. Once the image is positioned correctly go to the right-hand side of the screen and select "engrave" next to "visualizer:", as seen in the Figure 25 below.

Figure 25: Engraving Parameter Window

b. Select , on the pop up screen select engrave, scroll down to the bottom of the screen, and select "Wood Engraving 500 DPI"

c. Click "print" at the bottom of the software

d. Now go to the Laser Cutter

e. On the laser cutter display the file should show up

   a. Select the file and press the play button to run the machine the cut

   b. * make sure the ALL extractor are running before you press play on the Epilog Laser Cutter.

Appendix R: cajón Construction Procedure

Laser Cutting (see Figure 26)

1. Gather 5 pieces of wood that are 30 cm x 50 cm x 1cm and 1 piece that is 30cm x 50xcm x 0.5cm
2. Cut the wooden boxes using the "Software Procedure Laser Cutting" in Appendix Q
   - 2 pieces: 29.5cm x 29.5cm x 1cm
   - 1 piece: 29.5cm x 47cm x 1cm w/ a 12 cm circular cutout
   - 1 piece: 29.5cm x 47cm x 1cm
   - 4 pieces: 29.5cm x 2cm x 1cm using the leftover wood from prior cuts
3. Engrave image on top or side pieces using the "Software Procedure Laser Engraving" in Appendix Q

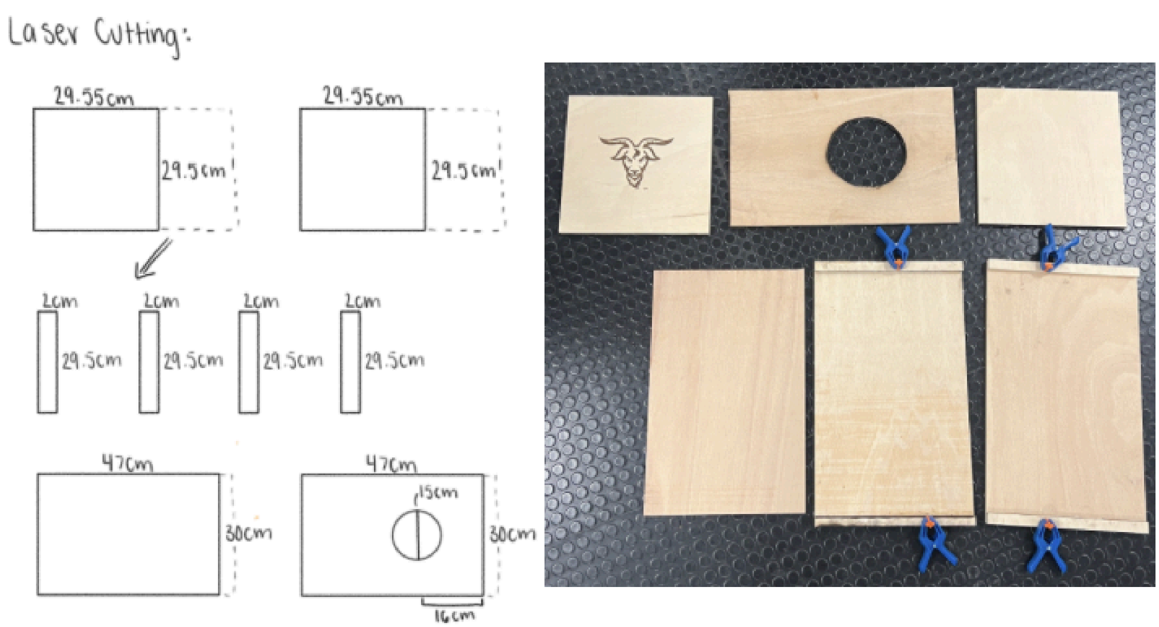


Figure 26: Final Cuts and Dimensions of cajón

Assembly

4. Glue the side pieces that are 29.5cm x 2cm x 1cm to the 2 uncut pieces of wood that are 29.5cm x 50cm x 1cm. Clamp the pieces and let dry for 24 hours (see Figure 27).

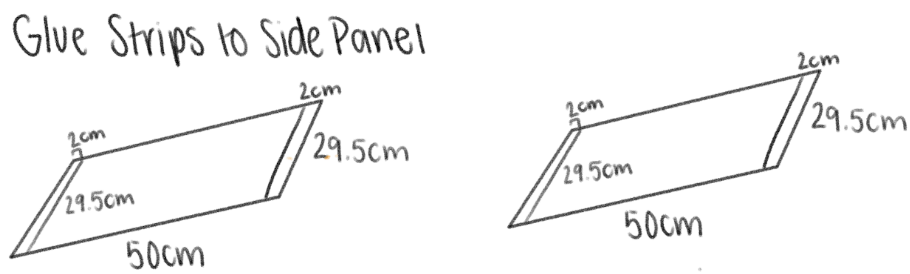


Figure 27: Side Panel Construction

5. Glue the sides panels (29.5cm x 50cm x 1cm w/ 29.5cm x 2cm x 1cm addition) to the top panel by applying wood glue to the side panel with the additional strip for maximum surface area. Use 4 clamps to hold the edges together.
6. Let dry for about 30 minutes and then take 6 nails to nail the top piece down the sides to help with the structural integrity of the cajón.
7. Repeat step 5 and 6 for the bottom panel. See Figure 28.

Figure 28: Top and Bottom Panel Construction

8. Once dry, take the front panel which is 29.5cm x 47cm x 0.5cm and glue the bottom half of the panel to the cajón. Clamp it face down to let it dry. (see Figure 29)

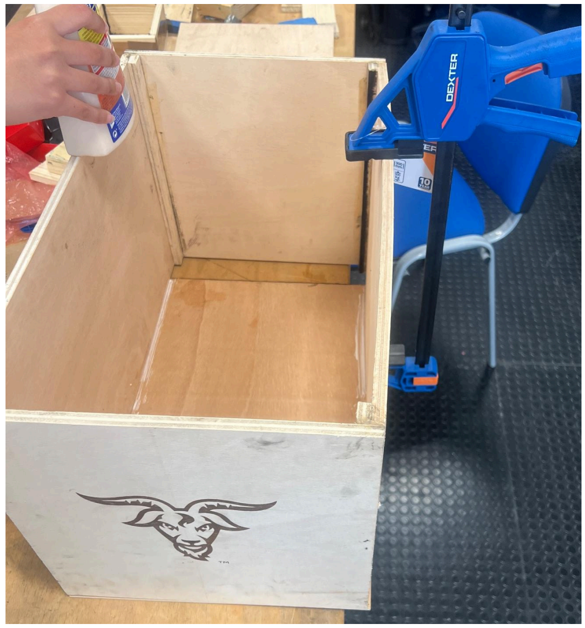


Figure 29: Front Panel Construction

9. While the front panel is drying, begin constructing the snares. Cut approximately 60 cm of wire using wire cutters.
10. Grab two scrap panels (size and length are negligible) and fold the wires evenly into a V shape over one piece. Place the other piece on top and use a clamp to create an imprint of the wires (See Figure 30).

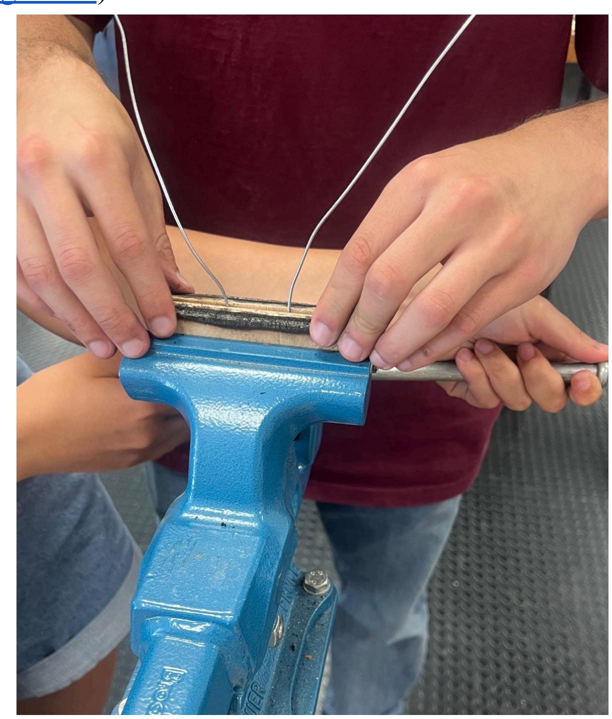


Figure 30: Building the Snares

11. Once there is little space between the pieces of the wood, glue them together, with the wire in between, and clamp the ends together. Let dry for 30 minutes.
12. Take the snare and place it at the front of the bottom panel, ensuring that the wires hit against the front panel. Glue and clamp the snare down (See Figure 31).

Figure 31: Adding Snares to cajón

13. The back panel will be hammered in to allow for access to the snares if adjustment is needed. Take the final panel that is 30cm x 47xm x 1cm with the open circle and mark points approximately 15 cm apart around the edges. Note: if you do not desire to re-open the back panel, wood glue will be sufficient and slightly easier.
14. Line up the back panel to the back of the cajón. Using 30mm nails, nail into the marks made on the back panel (See Figure 32).

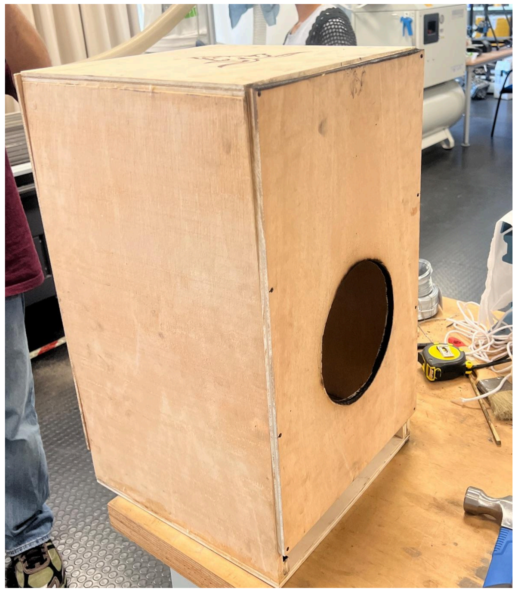


Figure 32: Attaching Back Panel of cajón

15. Let the cajón sit for 24 hours.
16. Once completely dry, apply a generous amount of varnish to the cajón to extend the instrument's durability and longevity. See Figure 33.

Figure 33: Completed cajón with Varnish

Appendix S: Program Manual and Daily Lesson Plan

Week 1

Day 1: Safety and Introduction

<table>
<tr><td>Lesson Title:
Safety in the Lab</td><td>Year Group:
All</td><td>Duration of Class:
90 minutes</td><td>Lesson # of #:
Lesson 1 of 9</td></tr>
<tr><td colspan="2">Fab Lab Learning Objective:
1. Intro to all the machines
2. Overview of the course
3. General safety
4. Laser cutting demo</td><td colspan="2">Cultural/STEM Integration Learning Objective:
1. What instruments we will be making and why (Flamenco + STEM integration)</td></tr>
<tr><td colspan="4">Activities and Timeline:

10 minutes: Introduction to the class
30 minutes: Safety Precautions
30 minutes: Machines Overview + Laser engraving Demo + Inkscape software overview
20 minutes: Instruments and Next Class Prep</td></tr>
<tr><td colspan="2">Instructor Materials Needed:

- Knowledge of Fab Lab
- Lab Safety powerpoint
- Have various instruments; Castanet, Kazoo, cajón
- Wood panel ready to go</td><td colspan="2">Student Materials Needed
- Notes and pencil</td></tr>
<tr><td colspan="4">Notes:</td></tr>
<tr><td colspan="4">Preparation for Next Class:

- Cultural Lesson class
- Gather resin materials to make a “C” keychain</td></tr>
</table>

Day 2: Safety and Introduction

<table>
<tr><td><u>Lesson Title:</u>
Flamenco & History</td><td><u>Year Group:</u>
All</td><td><u>Duration of Class:</u>
90 minutes</td><td><u>Lesson # of #:</u>
Lesson 2 of 9</td></tr>
<tr><td colspan="2"><u>Fab Lab Learning Objective:</u>
1. Resin activity!</td><td colspan="2"><u>Cultural/STEM Integration Learning Objective:</u>
1. Making resin - working with the scale measuring out values</td></tr>
<tr><td colspan="4"><u>Activities and Timeline:</u>

10 minutes: Introduction to the class
30 minutes: Overview of the Fab Lab - working with resin equation
25 minutes: Demo of Resin Activity; making the C from Cádiz Fablab
25 minutes: Students make their own + Customize it</td></tr>
<tr><td colspan="2"><u>Instructor Materials Needed:</u>
- Resin A
- Resin B
- Silicone molds
- Sparkles</td><td colspan="2"><u>Student Materials Needed</u>
- Paper and pens</td></tr>
<tr><td colspan="4"><u>Notes:</u>
- 60 g of resin A to 40 grams of resin B
    - Have students practice pouring and finding an appropriate amount for each “C”
- Students will be able to collect their resin C’s the next day</td></tr>
<tr><td colspan="4"><u>Preparation for Next Class:</u>

- Get ready to make Resin Castanets' next course
    - Gather wood, silicone and resin</td></tr>
</table>

Day 3: Castanets

<table>
<tr>
<td><u>Lesson Title:</u>
Resin Castanets!</td>
<td><u>Year Group:</u>
All</td>
<td><u>Duration of Class:</u>
90 minutes</td>
<td><u>Lesson # of #:</u>
Lesson 3 of 9</td>
</tr>
<tr>
<td colspan="2"><u>Fab Lab Learning Objective:</u>
1. Make Wooden box for castanet using laser cutters</td>
<td colspan="2"><u>Cultural/STEMl Integration Learning Objective:</u>
1. Use of Castanets in Flamenco</td>
</tr>
<tr>
<td colspan="4"><u>Activities and Timeline:</u>

10 minutes: Introduction and pass out materials
15 minutes: Epilog Software overview +
30 minutes: Laser Cutting the Wooden Box
● Software Procedure Laser Cutting Steps 1-10
30 minutes: Assemble the box
● Building the Wooden Box Steps 1-4</td>
</tr>
<tr>
<td colspan="2"><u>Instructor Materials Needed:</u>
- Castanet Procedure
- Wood Sheet to cut into 4 blocks
- Tape
- Hot wax gun
- Thin String
- Pol-ease 2500
- Clamp Stand
- String</td>
<td colspan="2"><u>Student Materials Needed</u></td>
</tr>
<tr>
<td colspan="4"><u>Notes:</u>
- Be sure to pass out the resin C’s from the prior day
- If time permits move into Week 2, Day 1 of Creating the silicone mold</td>
</tr>
<tr>
<td colspan="4"><u>Preparation for Next Class:</u>
- Silicone molds</td>
</tr>
</table>

Week 2

Day 1 Castanets

<table>
<tr>
<td><u>Lesson Title:</u>
Silicone Molding</td>
<td><u>Year Group:</u>
All</td>
<td><u>Duration of Class:</u>
90 minutes</td>
<td><u>Lesson # of #:</u>
Lesson 4 of 9</td>
</tr>
<tr>
<td colspan="2"><u>Fab Lab Learning Objective:</u>
1. Preparing Silicone
2. PPE with Chemicals</td>
<td colspan="2"><u>Cultural/STEM Integration Learning Objective:</u>
1. Math - Silicone A and B ratio work</td>
</tr>
<tr>
<td colspan="4"><u>Activities and Timeline:</u>

20 minutes: Introduction + Disperse Materials
20 minutes: Prep setup for Negative Mold
● Building the Wooden Box Steps 5-6
10 minutes: STEM integration (see Cultural/STEM Integration Learning Objective)
40 minutes: Measuring & Mixing Silicone A/B; Pouring the Mold
● Silicone Molding - The Negative Steps 7-9</td>
</tr>
<tr>
<td colspan="2"><u>Instructor Materials Needed:</u>
- Castanet Procedure
- Wooden Block
- Castanet
- Clamp Stand
- String
- Silicone A/Silicone B</td>
<td colspan="2"><u>Student Materials Needed</u></td>
</tr>
<tr>
<td colspan="4"><u>Notes:</u>
- Students will not be working directly with the chemicals; the instructor will work with each team to prepare everything and the students can pour the mold into the box</td>
</tr>
<tr>
<td colspan="4"><u>Preparation for Next Class:</u>
- Resin Castanet molding</td>
</tr>
</table>

Day 2: Castanets + cajón

Lesson Title: Resin Work and Intro to cajón Fabrication	Year Group: All	Duration of Class: 90 minutes	Lesson # of #: Lesson 5 of 7
Fab Lab Learning Objective: 1. Resin Work 2. Laser cutting/computer work 3. 3d printing		Cultural/STEM Integration Learning Objective: 1. Castanet 2. cajón	
Activities and Timeline: 10 minutes: Introduction to the class 35 minutes: Castanet work - cut the molds and pour the resin ● **Casting the Resin** Steps 10-17 35 minutes: How to work on the computer to upload the cajón dimensions ● **Software Procedure Laser Cutting** Steps 1-10 10 minutes: Clean up			
Instructor Materials Needed: - Castanet Procedure - cajón Procedure - Boxcutter for Silicone Mold - Resin Mixture - Glitter - cajón Dimension/ Blueprint - Premade cajón		Student Materials Needed - Student can Brainstorm Designs for their panel	
Notes: - If multiple instructors are available, students can work simultaneously on the cajón and castanet; half finishes the castanet while the other half begins cajón and then flip			
Preparation for Next Class: - Laser Cut cajón Pieces - Come up with engraving designs, disperse papers at the end of class			

Day 3: Castanets + cajón

Lesson Title:	Year Group:	Duration of Class:	Lesson # of #:
Cutting the cajón	All	90 minutes	Lesson 6 of 9

Fab Lab Learning Objective:	Cultural/STEMIntegration Learning Objective:
1. Construction of Castanets 2. Laser cutting wood	1. cajón

Activities and Timeline:

10 minutes: Introduction and Disperse materials
15 minutes: Assemble Castanet
- **Final Touches** Steps 18-19

30 minutes: Laser cutting the wood
- **Software Procedure on Inkscape: Laser Cutting** Steps 1-10
- **Laser Cutting (cajón Procedure)** Steps 1-3

30 minutes: Engraving the wood on computer
- **Software Procedure on Inkscape: Laser Engraving** Steps 1-3

Instructor Materials Needed:	Student Materials Needed
- Castanet Procedure - cajón Procedure - Wood sheet - Computer with designs	

Notes:
- If multiple instructors are available, students can work simultaneously on creating the engraving designs and laser cutting the wood

Preparation for Next Class:

Week 3

Day 1: cajón

Lesson Title:	Year Group:	Duration of Class:	Lesson # of #:
cajón Assembly	All	90 minutes	Lesson 7 of 9

Fab Lab Learning Objective:	Cultural/STEM Integration Learning Objective:
1. Woodwork 2. 3d printing	1. Acoustics and Sound

Activities and Timeline:

10 minutes: Introduction
45 minutes: cajón assembly
- **Assembly** Steps 4-8

15 minutes: Acoustics (see learning objective)
20 minutes: Building the Snare
- **Assembly** Steps 9-12

Instructor Materials Needed:	Student Materials Needed
- cajón Procedure - Wood - Wood glue - Clamps	- Paper with engraving design

Notes:

- If multiple instructors are available, students can work simultaneously on creating the engraving designs and laser cutting the wood

Preparation for Next Class:

Day 2: cajón and Carnival Fluta

<table>
<tr><td>Lesson Title:
3d printing</td><td>Year Group:
All</td><td>Duration of Class:
90 minutes</td><td>Lesson # of #:
Lesson 8 of 9</td></tr>
<tr><td colspan="2">Fab Lab Learning Objective:
1. 3d printing
2. Finish cajón assembly</td><td colspan="2">Cultural/STEMIntegration Learning Objective:
1. Carnival History</td></tr>
<tr><td colspan="4">Activities and Timeline:

10 minutes: Introduction to the class
20 minutes: Final touches to cajón
● Assembly Steps 14-16
20 minutes: Carnival History
30 minutes: 3d printing kazoo</td></tr>
<tr><td colspan="2">Instructor Materials Needed:
- cajón Procedure
- Wood glue
- PLA for 3D printer</td><td colspan="2">Student Materials Needed</td></tr>
<tr><td colspan="4">Notes:</td></tr>
<tr><td colspan="4">Preparation for Next Class:</td></tr>
</table>

Day 3: Carnival Fluta

<table>
<tr><td>Lesson Title:
3d printing</td><td>Year Group:
All</td><td>Duration of Class:
90 minutes</td><td>Lesson # of #:
Lesson 9 of 9</td></tr>
<tr><td colspan="2">Fab Lab Learning Objective:
1. 3d printing Kazoo
2. Finish cajón assemble</td><td colspan="2">Cultural/STEM Integration Learning Objective:
1. Sound and Accoustics - cajón</td></tr>
<tr><td colspan="4">Activities and Timeline:

10 minutes: Introduction to the class
80 minutes: Continue printing</td></tr>
<tr><td colspan="2">Instructor Materials Needed:
- STL file for Kazoo
- PLA for 3D printer</td><td colspan="2">Student Materials Needed</td></tr>
<tr><td colspan="4">Notes:</td></tr>
<tr><td colspan="4">Preparation for Next Class:</td></tr>
</table>