Interactive Music Science Collaborative Activities

Team Teaching for STEAM Education

Deliverable 2.3
Initial Educational scenarios and lesson plans for iMuSciCA

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Executive Summary

iMuSciCA stands for Interactive Music Science Collaborative Activities. The aim of this project is to achieve deeper learning in Science through the interaction between Music, Science and Engineering in a digital environment, the iMuSciCA workbench, in which students will be able to experiment, design, print and let sound their own virtual musical instruments.

In this framework, the iMuSciCA STEAM pedagogical framework has been developed, combining the Inquiry Based Science Education model with the integration of the three STEAM fields: Science-Mathematics, Music and Engineering. The pedagogical team has researched the science misconceptions relevant to the iMuSciCA scope and explored the the connections of iMuSciCA to the National Curricula of the participant countries (France, Belgium, Greece), thus defining the desired learning outcomes for the end users of the project.

Following these developments, alongside the technical development of the iMuSciCA workbench, the iMuSciCA pedagogical team has designed the iMuSciCA initial educational scenarios, and proposes an "iMuSciCA curriculum" which is defined as a full sequence of educational scenarios which will be applicable to all national curricula either within the framework of school curricula or in the framework of project based work. Furthermore, a strategy for the implementation of pedagogical innovation in the educational scenarios for the future of the project is being presented.

This document builds upon Deliverable 2.1, "Initial Pedagogical framework and iMuSciCA use cases by learners and teachers" and presents the study performed in terms of national curricula and science misconceptions, presents the technological needs of the iMuSciCA educational scenarios, describes the structure of a scenario, demonstrates the initial scenarios that have been developed, discusses the proposed "iMuSciCA curriculum" and presents a strategy for the implementation of pedagogical innovation in the educational scenarios.

Version Log			
Date	**Version No.**	**Author**	**Change**
11-09-2017	0.1	Emmanuel Chaniotakis (EA), Petros Stergiopoulos (EA)	Initial structure
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02-02-2018	2.0	Evita Fotinea (ATHENA), Vassilis Katsouros (ATHENA)	Resubmission to the EU

Disclaimer

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LIST OF ABBREVIATIONS

Abbreviation	Description
STEM	Science, Technology, Engineering and Maths
STEAM	Science, Technology, Engineering and Maths combined with Arts
PU	Public Report
WP	Work Package
ATHENA	ATHENA RESEARCH AND INNOVATION CENTER IN INFORMATION COMMUNICATION & KNOWLEDGE TECHNOLOGIES
UCLL	UC LIMBURG
EA	ELLINOGERMANIKI AGOGI SCHOLI PANAGEA SAVVA AE
IRCAM	INSTITUT DE RECHERCHE ET DE COORDINATION ACOUSTIQUE MUSIQUE
LEOPOLY	3D FOR ALL SZAMITASTECHNIKAI FEJLESZTO KFT
CABRI	Cabrilog SAS
WIRIS	MATHS FOR MORE SL
UNIFRI	UNIVERSITE DE FRIBOURG

1. The iMuSciCA pedagogical framework and educational scenarios

1.1 The proposed STEAM pedagogy

As a STEAM-oriented project, iMuSciCA aims to design and implement a suite of software tools and services on top of new enabling technologies integrated on a platform that will deliver interactive music activities for teaching/learning STEM. iMuSciCA addresses secondary school students with the aim to support mastery of core academic content on STEM subjects (Physics, Geometry, Mathematics, and Technology/Engineering), alongside with the development of creativity and deeper learning skills through their engagement in music activities.

The iMuSciCA pedagogical framework tackles the challenge of students achieving deeper learning in science through the combination of Science-Mathematics, Music and Engineering in an interdisciplinary, interactive, online environment dedicated to virtual musical instrument creation. To achieve this goal, the pedagogical framework has to:

- Provide opportunities for students to master the core academic content addressed by iMuSciCA.
- Provide the ground for critical thinking and complex problem solving both in an individual and in a collaborative basis.
- Offer the students the opportunity to learn how to communicate effectively.
- Learn how to learn and develop academic mindsets.

The iMuSciCA pedagogical framework follows the Inquiry Based Science Education (IBSE) approach, embedded in a three-faced environment covering equally the STEAM fields of Science-Mathematics, Music, Engineering which are complementary to each other and equally contribute to goals like creating a virtual musical instrument.

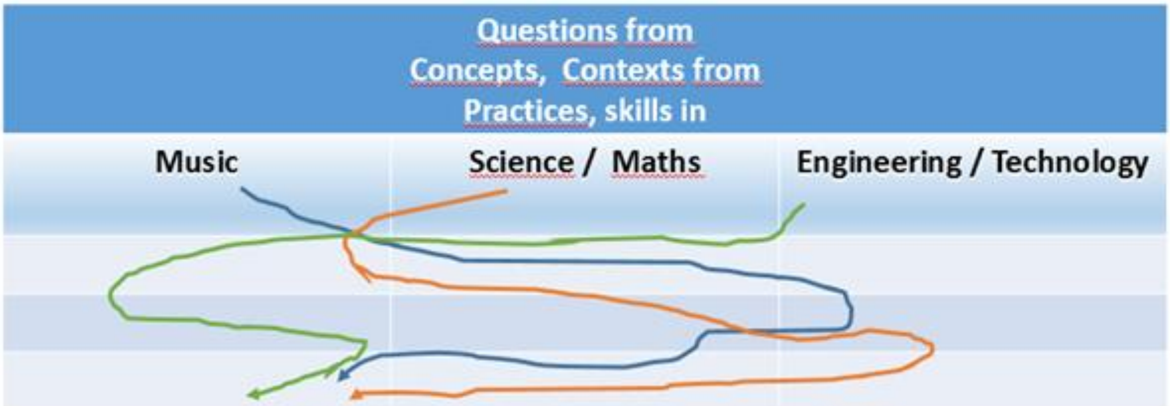


Figure 1.1.1: The interplay between the three STEAM fields during the course of an iMuSciCA scenario

The inquiry phases addressing the goals of the pedagogical framework are briefly described in Table 1.1.1:

Table 1.1.1: The iMuSciCA inquiry phases

Inquiry Phase	***Sub-phases***
1. **Engage**	a. Wonder, Ask Questions, Explore, Observe– Identify Problems, questions and chances b. Relate to Background Knowledge
2. **Imagine7**	a. Identify relevant variables to investigate – Identify Relevant Solutions to use b. Use your imagination and make hypothesis – Choose potential solution
3. **Create (Investigate/Design)**	a. Plan the Investigation / Design the Prototype b. Carry out Investigation / Build the Prototype
4. **Analyze**	a. Analyze Data from Investigations and Draw Conclusions/ Evaluate the Prototype. b. Explain by Relating to Background Knowledge/ Optimize the prototype c. Describe and explain the results in the different STEAM-fields and the connections between them.
5. **Communicate/Reflect**	a. Communicate Results and Conclusions/ Communicate the Product, perform b. Reflect on Feedback and incorporate in further process

iMuSciCA inquiry phases and sub-phases merge fundamental aspects of scientific inquiry with the engineering cycle as well as aspects of music creation in a common pedagogical design.

During the implementation of an iMuSciCA scenario, students will:

- Engage with the topic and relate their results with already existent knowledge of theirs.
- Imagine in order to create their own hypotheses and identify relevant solutions to the problem they address
- Create by planning and carrying out an investigation or creating and building a prototype.
- Analyze the result of their investigations, evaluate the prototype they created, optimize their results and draw conclusions.
- Communicate their results and conclusions to their peers and finally reflect on the procedure they followed and on the feedback they received and incorporate it in further process.

Despite the sequential nature of the Inquiry Phases, the iMuSciCA pedagogical design offers the opportunity for an iterative approach, during which some Inquiry Phases can be revisited, by addressing the relevant lesson plans or adding new ones.

Students work in both individual and collaborative basis, exploring the academic content of the scenarios in depth, in a hands on fashion using cutting edge e-learning tools. They also enhance their problem solving skills and critical thinking through the inquiry based structure of the pedagogical approach as well as through problem solving tasks presented in the educational scenarios. Furthermore, by communicating their outcomes and reflecting on the procedure followed, the students learn how to learn and how to communicate effectively.
During each inquiry phase, students interact with at least one STEAM field, whereas during the implementation of a scenario, all STEAM fields and inquiry phases are met at least once.
As a result, the proposed pedagogy contributes to the goal of providing a framework for students achieving deeper learning of science through an interdisciplinary, inquiry-based, STEAM approach. For further information on the iMuSciCA pedagogical framework, the reader is encouraged to consult **D2.1:** *"Initial Pedagogical framework and iMuSciCA use cases by learners and teachers"*.
For further information on the evaluation metrics and methodology of addressing Deeper Learning in the framework of iMuSciCA, the reader is encouraged to consult **D2.2**: *"Initial Evaluation Metrics for Deeper Learning With iMuSciCA"*.

1.2 The iMuSciCA educational scenario architecture

In this section, the method of implementation of the iMuSciCA pedagogical framework into educational content is discussed. The architecture of the iMuSciCA educational modules has been designed taking into account the following factors:

a. The iMuSciCA pedagogical framework.
b. The need to provide the means for students to achieve Deeper Learning of STEM.
c. The need for flexibility in order to adapt the modules in the classroom reality.

The need to follow the iMuSciCA pedagogical framework is addressed by creating the iMuSciCA educational scenario template in a fashion that includes all inquiry phases and STEAM fields. The pedagogical phases of iMuSciCA can be applied linearly or iteratively, allowing students space to engage effectively both in a structured and in a free fashion.
To address the need to provide the means for students to achieve Deeper Learning of STEM through iMuSciCA, a long term exposure is desired for students involved in iMuSciCA implementation activities. As a result, the minimum level of student engagement has been defined as the time needed to complete an educational scenario, the duration of which is at least 4 school hours, with a desired estimated time of 8 school hours. No upper time limit is defined per scenario.

The variations between the participant countries' National Curricula, the structural differences between the public schools, music schools and private schools as well as the everyday classroom reality provide a landscape which requires flexibility and adaptability in the architecture of iMuSciCA educational modules. Taking into account these factors, the design of the educational modules should be such that can adapt in long term project based work that can be carried out in school clubs, in medium term regular classroom interventions dedicated to iMuSciCA or in short termed classroom interventions which go on par with the school curriculum, the last two depending on the school's flexibility and availability.

In this framework, a modular architecture has been developed for the iMuSciCA educational scenarios. One Educational Scenario, incorporating all IBSE inquiry phases and all STEAM fields and having duration of at least 4 hours, consists of smaller modules of lesson plans. Each lesson plan may incorporate one or more inquiry stages and has a typical duration of 1-2 school hours. Scenarios can be further combined in order to produce an iMuSciCA project, which consists of at least 1 scenario and its duration can span from 20 hours to the whole school year.

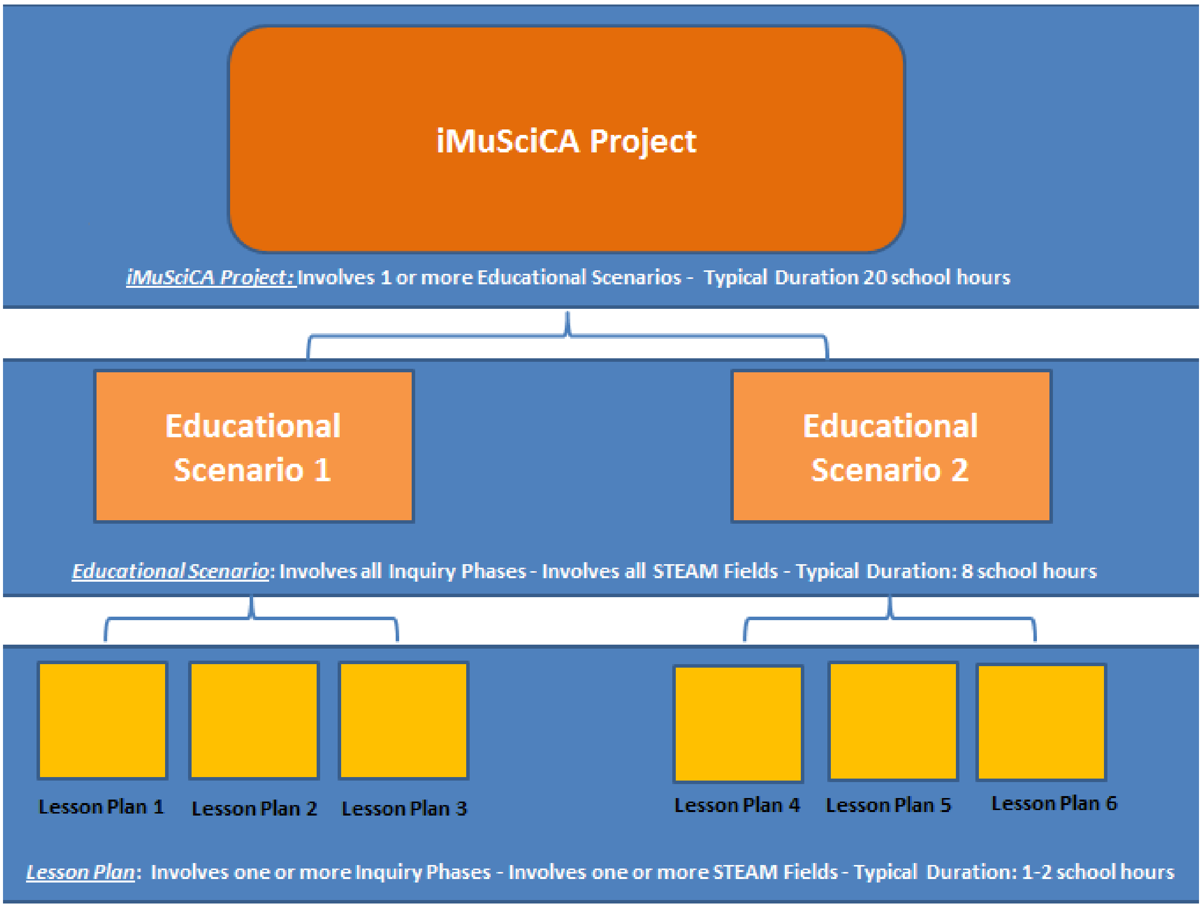


Figure 1.2.1: The modular architecture of iMuSciCA educational scenarios.

This structure allows not only flexibility with respect to the implementation setting, curriculum and time availability but also in the scenario design. As a scenario consists of Lesson Plan modules which involve one or more Inquiry Phases and STEAM fields, lesson plans can be combined, varied and rearranged in order to provide different educational scenarios.

1.2.1 Lesson Plan Metadata

Each lesson plan separately has a set of metadata section which need to be filled by the respective author. These metadata can be found in table 1.2.1.1

Table 1.2.1.1: Lesson Plan Metadata with potential options provided

Title:			
Keywords:			
Short Description:			
Inquiry Phases: Addressed	**1. ENGAGE** **2. IMAGINE** **3. CREATE (INVESTIGATE/DESIGN)** **4. REFLECT** **5. COMMUNICATE**	**STEAM Fields Addressed:**	**Music / Science / Technology**
Educational Objectives:		**Specific Field:**	

Author(s):		**Date:**	
Contributor(s):		**Estimated Duration:**	
Status:	**Draft / Final**	**Age Group:**	**10-12/12-14/14-16/16-18**
Dissemination level:	**Public/Custom**	**Language:**	
Interactivity:	**High/Medium/Low**	**Difficulty Level:**	**High/Medium/Low**
Technological Aggregation:	**Can be done only online/ Can be done without PC/ Has both online and PC components.**	**Special Needs Addressed:**	**Yes/No**

Table 1.2.1.1 describes the Lesson Plan Metadata found in each Lesson Plan template. Filling the metadata is obligatory for authors, as these lesson plans will be further aggregated to create educational scenarios.

1.2.2 Educational Scenario Metadata

Similarly, to lesson plans, educational scenarios have their own set of metadata that needs to be filled. These metadata can be found in tables 1.2.2.1 and 1.2.2.2.

Table 1.2.2.1: Educational Scenario Metadata

Title:			
Keywords:			
Short Description:			
Lesson Plans included:	Lesson Plan 1: Title & Link Lesson Plan 2: Title & Link ….	Date:	
Educational Objectives:		Estimated Duration:	
Author(s):		Age Group:	10-12/12-14/14-16/16-18
Contributor(s):		Language:	
Status:	Draft / Final	Difficulty Level:	High/Medium/Low
Dissemination level:	Public/Custom	Special Needs Addressed:	Yes/No

Table 1.2.2 is also mandatory to be filled by the author. It summarizes the relationship between lesson plans and scenarios in terms of inquiry phases and STEAM fields. The numerical value next to each "Lesson Plan" label, indicates the sequence of lesson plan implementation within the educational scenario framework.

Table 1.2.2.2: Table presenting the analysis of an educational scenario in its constituent lesson plans with STEAM field and Inquiry Phase reference per module.

	STEAM Field			
Inquiry Phase		**Music**	**Science/ Mathematics**	**Engineering/ Technology**
	Engage	*Lesson Plan 1*		
	Imagine		*Lesson Plan 1*	
	Create Investigate/Design	*Lesson Plan 4*	*Lesson Plan 2*	Lesson Plan 2
	Analyze		*Lesson Plan 3*	
	Communicate & Reflect	*Lesson Plan 4*	*Lesson Plan 3*	

It is also possible that all inquiry phases are present within one lesson plan, and thus this lesson plan is by itself an educational scenario.

Table 1.2.2.3: Table representing all inquiry phases in the same lesson plan.

	STEAM field			
STEAM Inquiry Phase		**Music**	**Science /Math**	**Engineering /Technology**
	Engage	*Lesson 1*		
	Imagine		*Lesson 1*	
	Create *Investigate/Design*	*Lesson 1*	*Lesson 1*	*Lesson 1*
	Analyse		*Lesson 1*	*Lesson 1*
	Communicate & Reflect	*Lesson 1*	*Lesson 1*	

1.3 The iMuSciCA Learning Management System

The iMuSciCA lesson plans will be written in the Cabri environment (https://cabri.com/en/) and uploaded on Moodle (https://lms.imuscica.eu) where students will be able to use them.

As a minimal example of the implementation of the iMuSciCA architecture in the Learning Management System the reader is encouraged to see Figure 1.3.1.

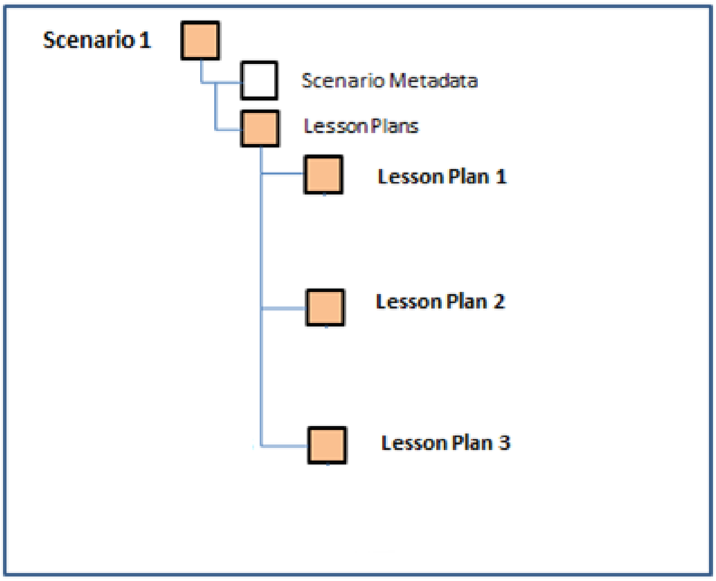


Figure 1.3.1: The iMuSciCA scenario architecture in the Learning Management System

The Moodle environment allows to:
1. Create new lesson plans starting from an **iMuSciCA Template**
2. Collect several lesson plans in order to form a new learning scenario
3. Take several scenarios into a project.
4. Make and edit (pre- and post-) questionnaires that can be put anywhere in lesson plans, scenarios and in projects.
5. Make questionnaires that can have open and closed questions.

The author can:
1. define the order of phases in the design of a lesson (not necessarily in the pre-defined order, as some phases can occur twice or more and others can be left out);
2. reuse existing lesson plans, while creating new ones;
3. reuse and edit existing questionnaires to assemble new ones.

The teacher can:
- drag new and existing lesson plans together to form a new scenario
- drag several scenarios together to form a project
- share scenarios and lesson plans: co-authoring also should be encouraged.
- work on drafts that can later be published

The system keeps metadata of every lesson plan, every scenario and every project.
Teachers can adapt metadata after altering a lesson, scenario or project. These metadata are explained in tables 1.2.1.1, 1.2.2.1, 1.2.2.2.

2. National Curricula and Relevance to iMuSciCA

2.1 Introduction

One of the major factors that need to be taken into account while designing effective educational scenarios for iMuSciCA implementations is the structure of the National Curricula in the participant countries. A thorough study of the French, Belgian and Greek National curricula has been conducted and the components relevant to the iMuSciCA scope have been identified. The study highlights the

opportunities provided per country in terms of potential project based iMuSciCA interventions, the margin provided in each participant country for curriculum interventions, as well as the different traits that need to be taken into account for adapting the iMuSciCA scenarios in the everyday school practice. All curricula have a common ground for implementation to 14-year-old students.
Each of the sections 2.2, 2.3 and 2.4 presents the results of the search on the French, the Belgian and the Greek curriculum respectively and summarizes the key points.

2.2 The French Curriculum

	French Curriculum
Upper Primary School and Junior High School	**Earlier years: discussion about signals in general** *In earlier grades, we do not speak about or study waves per se. The teaching is more diffuse and more build about the concept of "signal".* **Cycle 3 (age 9-10-11): Sound waves, electromagnetic waves. Frequency domains**. · Extract and use information about the nature of the waves and their frequencies as a function of the medical application. · Knowing an approximate value of the speed of sound in the air.
Junior High School	**Cycle 4 (age 12-13-14)** **Physics Education** Signals to observe and communicate **Maths Education** In Cycle 4, the student develops his intuition from a mode of representation to another one: numerical, graphic, algebraic, geometric, etc. These registry changes are favored by the use of versatile software such as spreadsheet or dynamic geometry software. Measurement and magnitudes: Calculate with measurable quantities; Express the results in the adapted units **Music Education** - Vocabulary and techniques of musical interpretation and expression (domains of dynamics, phrasing, Timbre, rhythm, pitch, shape, etc.). Simple numerical tools to capture sounds (recording), manipulate them (timbre) and organize them in time (sequence). Creation steps: pre-existing song or text; Notions of prosody. Example: Creation of short creations (voices, acoustic and electronic sound sources) in the style of a piece studied elsewhere. Realization in small groups of digital creations on specifications and comparison of the performances interpreted. Manipulate several forms of graphical representation of music using digital tools. Lexicons of musical language (stamp and Space, dynamics, time and rhythm, form, successive and simultaneous, styles). Example: Research on the physiology of hearing and the physics of sound; - Notions of acoustics and physics of sound; The notion of Decibel (Db), the compression of sound. **Technology Education** In connection with the visual arts, music education, French, mathematics. - Architecture, art, technology and society; The impact of technology and digital technology on our relationship to art, sound, music and information
Senior High School	**Physics Education** **Grade 10 (Seconde) For all students of general and technological high schools** Sound waves, electromagnetic waves. Frequency domains. Expected competencies: Extract and exploit information concerning the nature of the waves and their frequencies according to the medical application. Know an approximate value of the speed of sound in the air. **Grade 12 – Major in maths and science (Série S)** Swell, seismic waves, sound waves. Magnitude of an earthquake on the Richter scale. Level of sound intensity.Progressive waves. Associated physical magnitudes Delay. Periodic progressive waves, sinusoidal waves. Sound and ultrasonic waves. Spectral analysis. Height

	and timbre. Doppler Effect. *<u>Example: Carry out the spectral analysis of a musical sound and exploit it to characterize the height and the timbre</u>* **Optional speciality: Sound and music** <u>Musical instruments:</u> - Stringed instruments, air instruments, percussion instruments - Electronic instruments <u>Sound transmitters and receivers</u> - Voice, physiologic acoustics -Microphone, Loudspeakers, headphones. <u>Sound and Architecture</u> - Auditorium; Soundproof room. - Active acoustics; reverberation. - Speech Recognition **<u>Maths education</u>** **Grade 12 – For all students of general and technological high schools** Trigonometric Functions **Grade 12 – Major in sciences and mathematics (série S)** Calculus Functions sine and cosine: Know some properties of these functions, in particular periodicity and evenness or oddness. Know the graphical representations of sine and cosine. Link with progressive sine waves, mechanical oscillator in physics teaching. **<u>Music education</u>** No compulsory education in music. There are 3 kinds of different optional courses for the “lycée” but they are not available in each high school “lycée”. - Exploration optional teaching at grade 10 Optional instruction in all general and technological classes from grade 10 to 12. - Speciality teaching at grade 11 and 12 in Literature (L) sections, music and dance techniques (TMD) in technological sections. **<u>Grade 10: 15 to 16 year-old students</u>** An optional exploration course (Only in some “lycées”) Creation and artistic activity (1h30 per week) 4 possible domains: Visual arts, Sound arts, Performing arts, Heritage The student chooses one of these domains. These exploration courses propose to discover a disciplinary field, its social stakes and its place in the professional field. Through exploration and discovery, it is a matter of enlightening the choice of a possible continuation of study in a related field in the final cycle and then in higher education. The teaching of exploration of the sound arts offers high school students the opportunity to observe, analyze and understand the core of the "operator" of sound and music (venue, studio, etc.) profession and build knowledge on sound, music, entertainment and their places in society. **<u>Grades 10 - 11 – 12: 15 to 18 year-old students</u>** Optional course on arts (3h per week, additional to the compulsory part) with 6 possible domains. One of them is Music. When their institution proposes, students can enrich their training with an optional musical education leading to a specific examination for the baccalauréat. Following the compulsory education of the college, this teaching develops two essential skills (making and listening to music) and enriches a musical and artistic culture open to the diversity of aesthetics and genres. **<u>Grade 10 – 15 to 16 year-old students</u>** Excerpts of the program for Music Through the permanent articulation of the two components, practical and cultural, the optional teaching of music In second pursues the following general objectives: -discover, understand and experience diversified musical expressions;

	- to enrich a musical and artistic culture backed by the works studied and interpreted; - to develop a critical autonomy within its musical practices; -know and use resources from the daily cultural environment (technologies, the Internet, Venues for the training and distribution of the show). Musical Practice: voice and instruments - Interpret, arrange, improvise and even invent and create. Musical and artistic culture: enrichment of the musical culture of the students. **<u>Grade 11 – 16 to 17 year-old students</u>** Excerpts of the program for Music Two major questions irrigate the work of the year. The first examines the relationship of music to other fields of artistic creation, the second studies the various ways in which music organizes the time of its discourse, that is, its form. *Music and other arts* Links with text, movement and space, with image. Details not translated *Music and form* Forms of the musical language Details not translated **<u>Grade 12 – 17 to 18 year-old students</u>** Excerpts of the program for Music Music, timbre and sound (summary) Historical study of the diversity of timbres in relation with the creation of instruments New contemporary sounds It is through the study of several remarkable works chosen at different times that this problem and the many questions that arise will be addressed. Music, rhythm and time Measure, tactus, tempo, motif, theme, sentence, fixed forms and their refusal, harmony, dissonance, polyphony, density, etc. Music, interpretation and arrangement Music, diversity and relativity of cultures **<u>Speciality teaching</u>** **<u>Grade 11 and 12 - A specific Baccalaureat</u>:** Literature and arts in some schools with an option to choose among Cinema, Theater, Plastic Arts, Dance, History of arts, Music Again the preparation of this Baccalauréat takes place only in some schools and the schools do not necessarily propose the option Music. No compulsory teaching of mathematics. In terms of objectives, the ambition of this music teaching can be summarized according to the following axes: - allow a critical grasp of the knowledge and skills required to practice music (interpreting, creating, listening, etc.); - possess a rigorous and equipped method of analysis allowing the critical commentary of any musical situation; - chronological and diachronic (history of music and the arts) and geographical and synchronic (contexts, diversity and relativity of cultures) to develop a knowledge of the styles, genres and aesthetics that organize creation; - to diversify and enrich creative approaches in the arts, music and sound field: from passive listening to active listening, from recording to live performances, from acoustics to electronics (and vice versa), etc.; - to discover and to know elements of the contemporary artistic and musical life in the diversity of its facets. Competencies Perceiving: developing auditory acuity in the service of organized and problematized knowledge of musical and artistic cultures in time and space;

	- Producing: practicing the languages of music in order to develop a mastered artistic expression, individual or collective; Diversifying the practices and the repertoires encountered. - Thinking about music in the world today. **<u>Grade 11 and 12 - A specific technological (not general) Baccalaureat: Dance and Music</u>** Students must pass an examination to be accepted, in order to assess their level in music (in a small number of schools) Mathematics and physics course are compulsory

<u>Conclusions for France</u>:
The probability of finding students following an optional course in music is rather weak. There is a restricted number of high schools in which it is possible. In the framework of music education, following the already existing knowledge on sound waves from primary schools, students can investigate the basic characteristics of sound. The French curriculum of upper secondary gives somewhat less opportunities for iMuSciCA. The most important opportunities lie in the lower secondary (cycle 4 - 12 to 15 year-old students). Although, the context with music, science and technology, might be quite new there too, there are many chances where iMuSciCA can help realize the objectives of the curriculum and that of the newly implemented curricula reform.

2.3 The Belgian Curriculum

	Belgian Curriculum
Junior High School	**Secondary school 1st stage (middenschool) – 2nd year (12-14 years-old):** **<u>Physics Education</u>** *Wetenschappelijk werk – 3 hours/week* Context *licht en geluid* à *Light and sound* Vibration as source of sound Sound propagate as a pressure wave through a medium **<u>Music Education</u>** · Attention for playing music: vocally, instrumentally, design music · Listen to sound and music · Music and sound as a form of human expression · Recognize musical instruments on the basis of timbre · Distinguish melody, rhythm, tempo and dynamics in music · Distinguish musical forms · Musical notation in a graphical score of the pitch, dynamics, duration · Use devices to play music or to record music · Play music in group · Music and the human body and music and technology **<u>Subject "STEM":</u>** STEM – is a new subject in Flemish secondary schools; some hours/week depending on the school. No national curriculum: the school and teachers are free to develop a curriculum. iMuSciCA content can fit directly in this interdisciplinary subject.
Senior High School	**<u>Secondary school 2nd stage (15 -16 years-old):</u>** **<u>Biology Education</u>** Subject biology: 3 - 4 lesson hours on *sound and hearing* **<u>Music Education</u>** Focus on: play music individually and in group Music in different cultures: different musical scales **<u>Subject "STEM":</u>** STEM – is a new subject also in the second stage in Flemish secondary schools. iMuSciCA content can fit in this interdisciplinary subject. However, there are far less schools with

	STEM hours in the 2nd stage than there are in the 1st. **<u>Secondary school 3rd stage (17-18 years-old):</u>** **<u>Physics Education</u>** *waves and vibrations*, 11-18 hours in the last year. -Eigen frequency: activity about natural tones; changing the parameters of a system changes the frequency: activity about the border conditions of a system (changing length, etc…) -Propagation of sound as a wave -Wave-length, speed of waves, wave number … -The phenomenon of resonance -hearing -the conditions under which standing waves arise -For this stage we would need to add the mathematical equations with sinus.

<u>Conclusions for Belgium</u>:
For iMuSciCA there are possibilities both in the 1st (12-14 years old) stage as in the 3rd (17-18 years old) stage. Opportunities in the 2nd (14-16 years old) stage are somewhat more restricted. Especially the new subject STEM which many schools in the 1st stage set up, might be a good environment for piloting iMuSciCA.

2.4 The Greek Curriculum

	Greek Curriculum
Upper Primary School	**<u>Physics Education</u>** **5th grade elementary school:** Chapter on Characteristics of Sound. **<u>Music Education</u>** Pupils learn how to: ·Listen and respond in different ways to music as well as to rhythmic patterns. ·Produce simple sound patterns with voice, body and musical instruments. ·Perform at the same time as others, responding to the appropriate instructions. ·Perform rhythmic and melodic patterns from memory and symbols. ·Develop sound control capability in a variety of musical instruments. · Share music creation with different audiences. ·Design simple ways to store and transmit their musical ideas (symbolism). ·Explore, choose and control sounds in order to "compose" a simple piece of music. ·To "compose" and record their music for future recall using appropriate signs, symbols, slogans or other means. ·Listen and talk about sounds produced in different ways. · Investigate, select and combine sounds produced by musical instruments in order to produce simple compositions. · Store musical ideas and transmits them to others, using appropriate means. · Construct improvised musical instruments, similar to those of Greek traditional music and experiment with their use for the performance of songs.
Junior High School	**1st grade of Junior High School** **<u>Maths Education</u>** Chapter on equations Chapter on triangles and geometric shapes **2nd grade of Junior High School** **<u>Maths Education</u>** Chapter on functions and graphs Chapter on geometric solids **3rd grade of Junior High School** **<u>Maths Education</u>** Chapter on equations of the 2nd order

	Chapter on geometry Chapter on trigonometry **<u>Physics Education</u>** <u>Chapter on oscillations</u>: Period, Frequency, periodic phenomena <u>Chapter on sound</u>: wave equation, propagation in different media and empirical characteristics of sound. **<u>Music Education</u>** In terms of music education, one of the main tasks for students is to learn, get acquainted and use modern music technology. Students should also assume an active and responsible role in the design and presentation of voice and instrumental execution. They should also show ability to test and show performances. Students learn how to combine sounds in order to make their own. They use conventional or unconventional ways of noting a melodic ostinato and recall it accurately.
Senior High School	**1st Grade of Senior High School7** **<u>Maths Education</u>** Chapter on Equations Chapters on functions **2nd Grade of Senior High School** **<u>Maths Education</u>** Chapter on trigonometry **3rd grade of Senior High School (17 year olds) :** **<u>Physics Education</u>** Chapter on Physics of Oscillations Chapter on Physics of waves Equations, Wave Superposition, Standing Waves, Doppler Effect, sound. **<u>The Greek Music Schools</u>** Secondary education Music schools in Greece cover an extended daily curriculum with all disciplines of a "non-music" school plus an independent sector of disciplines specialized in music. Except from their normal school schedule, students learn an extended range of western and traditional musical instruments curriculum supported by individual lessons for each one along with music theory. A music school is considered to be the ideal environment for implementing the innovative teaching methods proposed by the iMuSciCA project. "Team-teaching for STEAM" approach is easily implemented in such schools as they fully support specialized curriculum in both Music and Science throughout secondary school years. More specifically the lesson of Music technology is introduced in 1st and 2nd grade "Lyceum" (Upper secondary) supporting the implementation of iMuSciCA learning scenarios related to Physics and virtual technology. Furthermore, students experiment with the development and manipulation of waveforms. They discover their properties by changing their characteristics using computer software oscillators and synthesizers. They also experiment with spectral analysis as part of the principles of digital recording.

<u>Conclusions for Greece:</u>

The Greek curriculum allows for interventions in year-long school clubs as well as for in-classroom during the Physics and Mathematics lessons for Greek Public and Private schools. The potential classroom interventions cluster mainly around the 3rd grade of Junior High School and the 1st grade of Senior High School (student ages of 14-15 years) throughout which the curriculum displays higher affinity with the iMuSciCA science and maths related content. Music Schools in Greece display a special case study, as the iMuSciCA interventions can be integrated both during the course of science related subjects, similar to the public and private schools in Greece, as well as during the course of specialized music and music technology related subjects provided in the framework of the Music School curriculum.

3. The iMuSciCA workbench and relevance to the educational Scenarios

3.1 Pedagogical dimension of the initial Workbench

The iMuSciCA workbench is an online virtual environment, currently under development, that provides students with the necessary tools and utilities in order them to address the different disciplines as they are: music, science/maths and engineering/technology and let them play, discover and design within and between those disciplines. By designing, creating, testing, optimizing, listening or even composing music or creating their own virtual musical instruments, they will discover connections between these STEAM-disciplines. Through the iMuSciCA workbench, students following an iMuSciCA scenario will be introduced to a unique, interdisciplinary STEAM learning experience.

The initial workbench provides an environment for learning experiences in these STEAM fields for investigating links between music and science, for creating and testing virtual instruments. The tools provided can be broadly grouped in three categories: Science-Mathematics, Music, Engineering. Moreover, some user learning analytics are being tracked and saved in a Learning Record Store in order to provide the data (complemented with further data collected from students and teachers) which intent to examine the achievement of deeper learning (See further WP2 deliverable D2.2-*Initial Evaluation Metrics for Deeper Learning with iMuSciCA*').

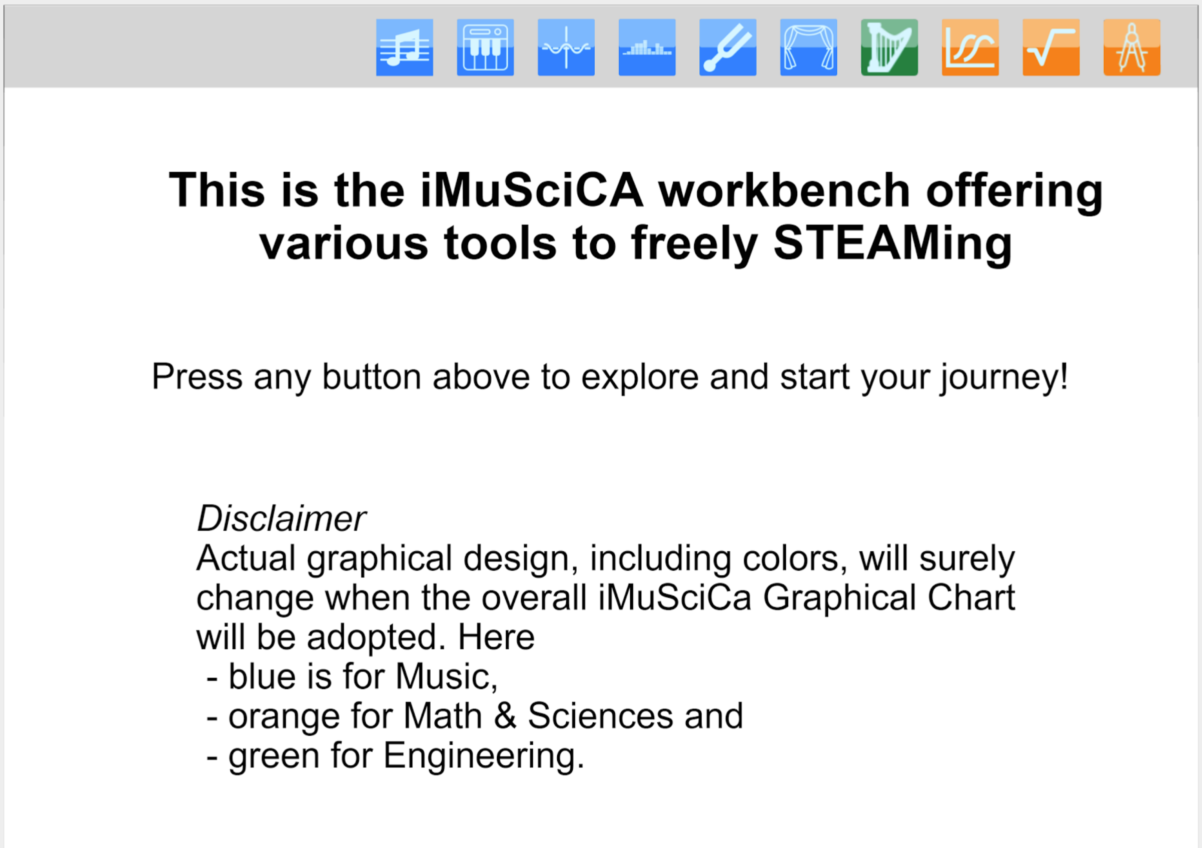


Figure 3.1.1: A first impression of the iMuSciCA workbench

Figure 3.1.1 shows a first mockup impression of the iMuSciCA workbench, which incorporates virtual tools belonging in the Science-Mathematics, Engineering and Music STEAM fields. As examples of the utilities provided by the iMuSciCA workbench, the user is able to perform operations such as the following: By choosing the engineering red tab on the top left of the workbench, the user is able to create and manipulate a virtual 3D musical instrument with all its relevant parameters as can be seen in Figure 3.1.1.

By choosing the science tab option, the user can perform simulations, analyze the waveforms, spectrograms and power spectra of the sound produced by the virtual instrument of their design, whereas by choosing the music tab the user can listen to the sound they produce, compose their own synthesis, perform sonification studies using a pen enabled canvas to listen to the music deriving from their own data, drawings and graphs. The users will be able to save the instruments of their design, process it further and then combine them in order to perform their own musical synthesis. The Workbench communicates with the LMS allowing the user to follow the instructions of a lesson plan throughout the virtual instrument design in the same window.

Besides the technological output of the iMuSciCA workbench, its main pedagogical innovation is the opportunity for the user to work interdisciplinary in the same virtual environment. The tools of the Science, the Engineering and Music tab are interconnected and these interconnections allow the users to become like young musical instrument designers, able to perform scientific measurements and compose their own music working individually or collaboratively. As an example, once the design parameters of the instrument are altered (through the engineering tab), the sound produced will sound different (music tab) and the sound waveforms and spectra will be altered accordingly (science tab). The iMuSciCA workbench is in the design phase and both the tools and the environment will undergo significant sophistication before the final working version is released.

3.2 Description of the initial individual instruments and tools

3.2.1 iMuSciCA musical instruments

Musical instruments can be categorized in three broad groups, according to their design and properties: stringed instruments, percussive instruments and wind instruments. The availability of instruments depends not only on the technical capabilities concerning CPU time on reproducing the real sound of these instruments but also on the complexity of their sonic body. By the end of the project, it is estimated that the users of the iMuSciCA workbench will be able to design and manipulate the following, among other instruments belonging to the aforementioned categories:

Example of a Stringed Instrument

The Monochord

Fig 3.2.1.1: *A monochord*

Monochords are defined as instruments with a single (or sometimes two) string(s) plucked between two fixed points. It consists of two parts: the body and the string. The string tension, the linear mass density (grams of mass per cm of length) and the length of the string are the parameters that define the frequency of the sound produced and as such, will be subject to manipulations by the users in the virtual environment. Users will be able to interact with the monochord through Leap Motion

tools.
Different ways of triggering the string of the monochord will be available, for example, through a bow or a hammer, whereas, the parameters relevant to the interaction of the user with the monochord will be the interaction point, the distance of the interaction tool to the string etc. In further stages, except from plucked instruments, the project will not exclude the possibility of studying the bowed chordophones as well. The sound production of bowed instruments is achieved by the transverse friction of hair-bundle across the string.

Example of a Percussive instrument

The Xylophone/ Glockenspiel

Fig. 3.2.1.3: A xylophone

The glockenspiel and the xylophone are percussion instruments composed of a set of **bars** arranged on a **board** in the fashion of the keyboard of a piano. The xylophone's bars are made of wood plates, while the glockenspiel's are metal plates or tubes. The bars are struck with **mallets** to produce musical tones. The interaction with the xylophone/glockenspiel is achieved through a mallet, it will consist of 5 parts (keys), and the parameters of significance for music production, able to be altered by the user will be: the length, the width, the thickness and the material.

Example of a Wind instrument

The pan flute

The wind instruments are foreseen to be developed at a later stage of iMuSciCA's. Aerophones require a particular study of complexity with regard to their sonic body, the ways and the conditions for temperature and pressure under which their sonic body is stimulated. The distinction between the two types of open or closed-end pipe-columns requires the determination of additional factors beyond their length, their diameter or their type. The simplest and typical example of an aerophone that can be studied within the workbench is the single open or closed-end tube.

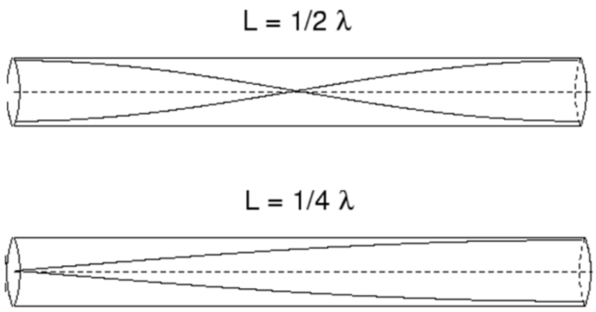


Fig. 3.2.1.4: Open and Closed-end tubes

Another example of a wind instrument that could be created in this framework is the pan flute: a set of close ended flutes with increasing length.

Fig. 3.2.1.5: The pan flute

Parameters that could be altered by the user in order to investigate the sound produced by the pan flute are the length of each flute, the width, the number of components of the pan flute or the step by which the individual length increases.

3.2.2 iMuSciCA individual tools

The iMuSciCA individual tools are virtual applications which will be included in the iMuSciCA workbench in order to allow users to achieve an extraordinary and interdisciplinary STEAM experience. The tools are divided in three broad subcategories: Science/Mathematics, Engineering and Music (for a first impression of this layout, please observe Figure 3.1.1.). In the context of this document, some representative tools from each STEAM field will be presented and discussed.

STEAM Field: Engineering/ Tool: 3D design environment

The iMuSciCA 3D design environment, developed by Leopoly, is the main engineering environment provided for users to experiment on, design and manipulate 3D virtual instruments. Users are able to perform 3D rotations, rearrange the shape of the instrument and manipulate important parameters per instrument through sliders and other options provided by the tool. In Figure 3.2.2.1 a first example of a virtual monochord is presented with the options to rotate and rearrange it (colored bubbles).

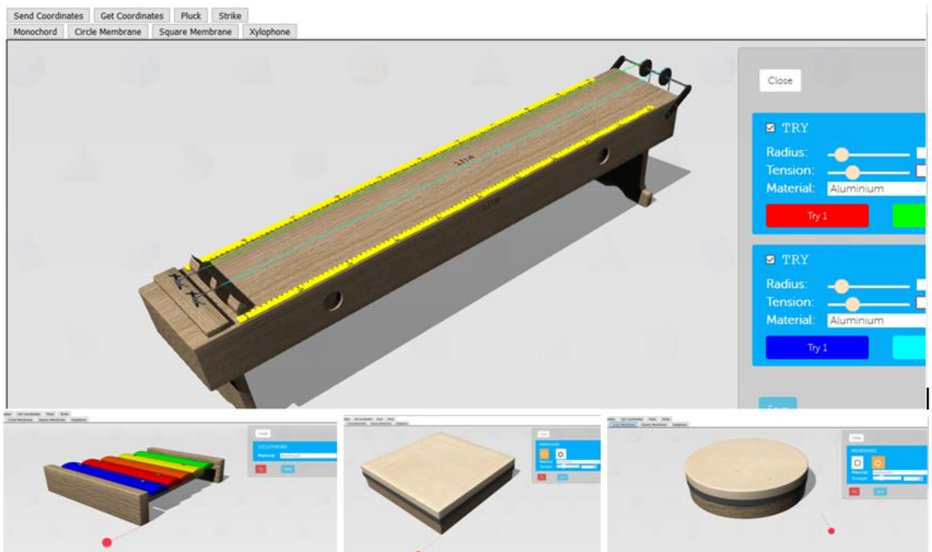


Figure 3.2.2.1: The iMuSciCA 3D design environment

STEAM Field: Science-Mathematics/ Tool: Geometry and algebra - Cabri Express

Cabri express is an under development online version of the Cabri tool, providing the tools for geometric, algebraic, numerical manipulations and simulations including the creation and processing of graphs.

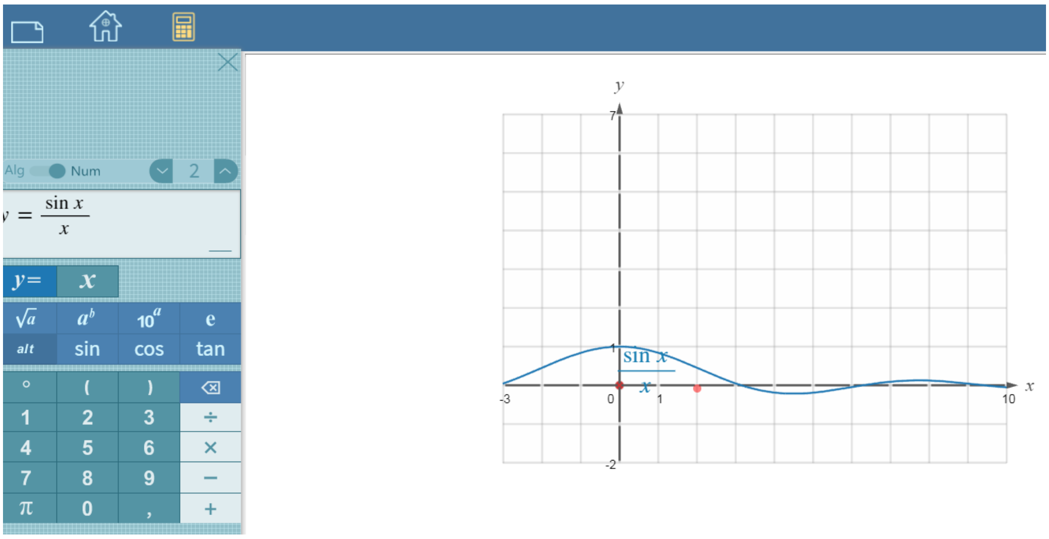


Figure 3.2.2.2: The online Cabri environment

STEAM Field: Science-Mathematics/ Tool: Sonification of mathematical equations and geometric curves

The sonification of mathematical equations and geometric curves tool, allows the user to draw their own shapes which the tool identifies with geometrical shapes, providing their equation in the scaled axes. As a next step, the user can play the sound of these shapes by performing sonification by frequency: The y-axis of the graph will be translated into frequency: as the y-value of the shape increases, so does increase the frequency of the produced sound.

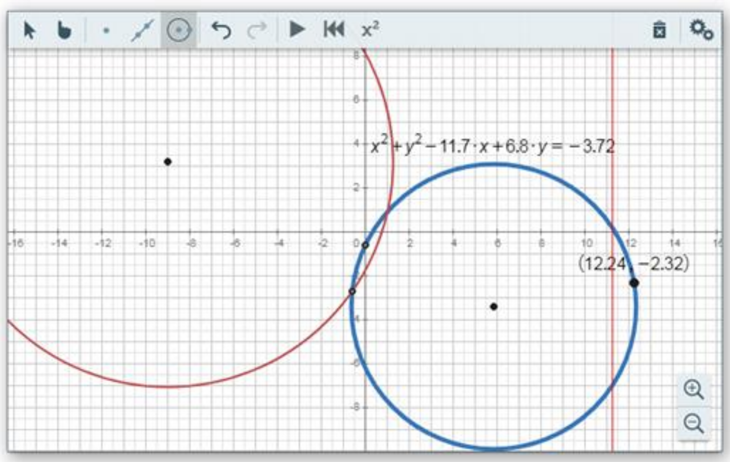


Figure 3.2.2.3: The sonification by frequency tool

STEAM Field: Music/ Tool: Drawing Canvas for Music Creation

The Drawing Canvas for Music Creation presents the users with the potential to draw shapes and sonify them. In this tool, the vertical axis represents notes and the horizontal axis represents time. Therefore, a straight line parallel to the horizontal axis represents a sound of fixed frequency. The windows on the right side of the monitor provide a real time waveform analyzer, a power spectrum and a spectrogram.

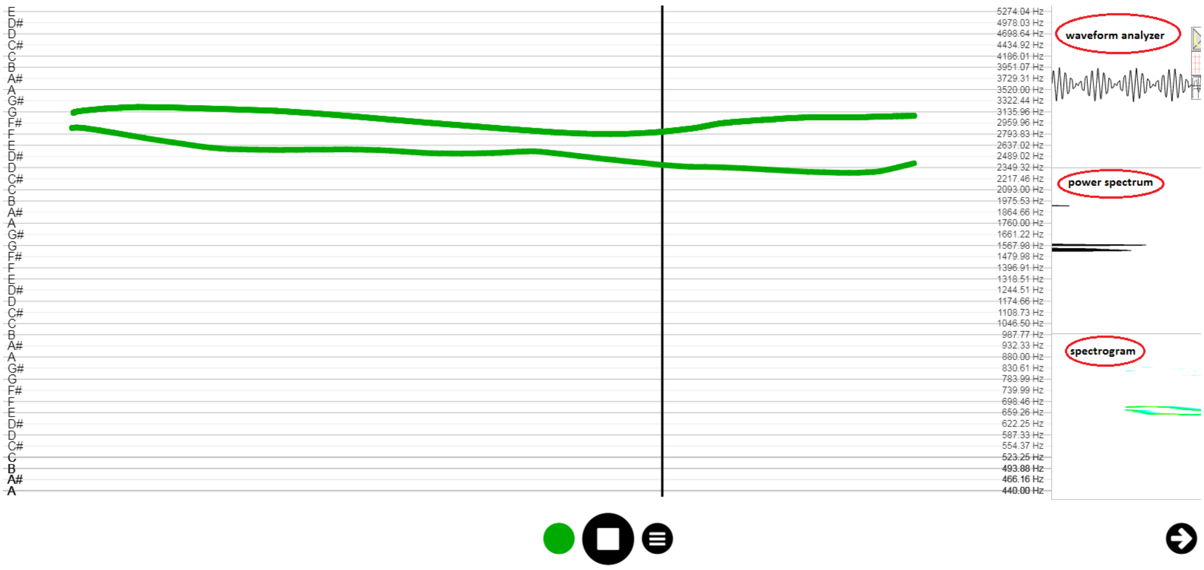


Figure 3.2.2.4: The Drawing Canvas

The tools presented here are representative of the larger set of tools already developed for the iMuSciCA workbench as well as those which are currently under development. The choice has been made in order to clarify the differences between the tools belonging to different environments.

For a more technical analysis on these and other iMuSciCA tools, the reader is encouraged to consult: D5.1- Initial 3D musical instrument interactive design kit, D5.2- Initial Music activities based on mathematical equations and geometric curves, D5.3- Initial Pen-enabled canvas for music and audio co-creation and interaction, D5.4 - Initial Gesture and VR tools for music interaction and co-creation and D5.5 - Initial Demonstrators of iMuSciCA workbench toolkits.

4. Developing a generic iMuSciCA curriculum

4.1 Rationale

In this section, the rationale for the creation of an iMuSciCA curriculum will be presented. This curriculum will consist of a sequence of educational scenarios which aim to: provide an engaging and meaningful educational experience exploiting the potential of the iMuSciCA workbench, help tackle misconceptions and difficulties of students in the iMuSciCA relevant fields and provide a paradigm on which educators, curriculum developers and researchers will be able to expand upon or create their own variations.

4.2 Definition of content difficulties and misconceptions relevant to the iMuSciCA scope

Mastering core academic content lies in the heart of the milestones one needs to reach in order to achieve deeper learning. In the framework of designing an effective iMuSciCA sequence of educational scenarios, which will be henceforth named: "The iMuSciCA curriculum", a thorough literature research has taken place in order to identify, choose and catalogue the student content difficulties and misconceptions relevant to the scope of iMuSciCA. These difficulties and misconceptions span from the Physics of waves and sound, aspects of Algebra and Geometry relevant to the design and output of musical instruments as well as concepts in Engineering which is as to know foreign to the most standard K12 curricula and are of paramount importance in the process of defining the learning outcomes of the iMuSciCA modules. Furthermore, student difficulties and potential misconceptions in Music will be explored. Music education and technology is treated in diverse manners per national curriculum and in the case of musical high schools, per school. As a result, a thorough investigation of this field is considered mandatory in the framework of the iMuSciCA scope.

4.2.1 Student misconceptions and difficulties in Physics

As most curricula treat sound as a subsection of wave physics, literature in sound-specific misconceptions is rather limited. The reader can visit table 4.2.1.1 in which the most important misconceptions related to the Physics of Waves and Sound, as well as their relevance to iMuSciCA are described.

Table 4.2.1.1: K12 students' misconceptions on waves and sound and their relevance to iMuSciCA

Topic	Misconception	Relevance to iMuSciCA
Physics of Waves and Sound	1. Sounds can be produced without using any material objects.	Relevant
	2. Hitting an object harder changes the pitch of the sound produced.	Relevant
	3. Human voice sounds are produced by a large number of vocal cords that all produce different sounds.	Relatively Relevant
	4. Loudness and pitch of sounds are the same things.	Highly Relevant
	5. You can see and hear a distinct event at the same moment.	Irrelevant
	6. Sounds can travel through empty space (a vacuum).	Relevant
	7. Sounds cannot travel through liquids and solids.	Relatively Relevant
	8. Sounds made by vehicles (like the whistle of a train) change as the vehicles move past the listener because something (like the train engineer) purposely changes the pitch of the sound.	Irrelevant
	9. In wind instruments, the instrument itself vibrates (not the internal air column).	Highly Relevant
	10. Music is strictly an art form; it has nothing to do with science.	Highly Relevant
	11. Sound waves are transverse waves (like water and light waves).	Highly Relevant
	12. When waves interact with a solid surface, the waves are destroyed.	Relevant
	13. In actual telephones, sounds (rather than electrical impulses) are carried through the wires.	Relatively Relevant
	14. Ultrasounds are extremely loud sounds.	Relevant (in terms of pitch and loudness misconception)
	15. Megaphones create sounds.	Relevant
	16. Noise pollution is annoying, but it is essentially harmless.	Relatively Relevant (understanding the amplitude of sound waves and humans' hearing physiology)
	17. Sound is a microscopic entity	Relevant

Physics of Waves and Sound	either carried by or transferred between molecules	
	18. Sound is a macroscopic entity with impetus like flowing air or a traveling pattern	Relevant
	19. Sound can be trapped in a container if the air is trapped-needs holes to escape	Highly Relevant
	20. Music has low volume (small amplitude) & noise has high volume (large amplitude)	Highly Relevant
	21. Longer objects vibrate faster, or produce higher notes	Highly Relevant
	22. Speed of sound-wave is affected by: force, sound-resistance, molecule separation	Relevant
	23. The sound box on a musical instrument is to make the sound clearer	Highly Relevant
	24. Sound waves cannot be refracted or bent like light	Relevant
	25. Vibrations and waves are the same thing	Highly Relevant
	26. Sound is unaffected by solid obstacles, passing right through them	Relevant
	27. Sound waves turn towards a hearer	Relevant
	28. Sound travels from the hearer to the source	Relevant
	29. Sound travels in electromagnetic Waves	Relevant
	30. Sound moves faster in air than in solids (air is "thinner" and forms less of a barrier).	Relevant
	31. The pitch of a tuning fork will change as it "slows down", (i.e. "runs" out of energy)	Highly Relevant
	32. the speed of sound is greater in the direction in which the source of the sound is moving	Relevant
	33. Matter travels with waves	Relatively relevant
	34. Wave collisions, according to the intuition of many students, result in the permanent cancellation of both waves, as if they were mechanical objects.	Relevant
	35. Students often confuse wave period with frequency.	Highly Relevant

Students seem to face problems in terms of the sources, the nature of sound as well as its propagation, many times perceiving it as a bounded entity travelling from one place to another, and despite mathematical formalism which appears to be understandable by students, the direct connection with waves is not clear in many cases. Furthermore, literature emphasizes the confusion of sound waves as being transverse instead of longitudinal.

Aspects such as the pitch (frequency) and the volume (amplitude) of sound waves and their interrelations, as well as the parameters affecting the velocity of sound, are commonly confused among students. Further topics that seem most difficult in the eyes of students who first encounter them are the principles of wave superposition, standing waves and the formation of beats, which can be clarified and addressed in a creative fashion through the interaction of students with musical instruments' basic functions such as tuning.

iMuSciCA can effectively deal with Physics of Waves and Sound misconceptions which are identified in Table 4.2.1.1 as relevant and highly relevant.

4.2.2 Student misconceptions and difficulties in Algebra and Geometry

K12 Student difficulties arise in the fields of Algebra and Geometry, both in terms of visualization and analysis of a specific problem. Furthermore, 3D Geometry being a topic not largely addressed in the standard K12 curricula, while it is paramount in the framework of designing a musical instrument is considered fundamental to be explored further.

Table 4.2.2.1 lists algebraic and geometric difficulties found in literature research and categorizes them according to their relevance to the iMuSciCA scope.

Table 4.2.2.1: K12 students' difficulties on algebra and geometry and their relevance to iMuSciCA

Topic	Contents and associated abilities	Relevance to iMuSciCA
Geometry	1. Identifying basic properties of triangles	Relevant
	2. Conservation misconception	Relevant
	3. Angles: Larger Space means larger angle	Relevant
	4. Identifying Shape Properties	Relevant
	5. Lines of symmetry, orientation and Rotation of Shapes in 2 and 3D	Highly Relevant
	6. Classification of triangles	Relevant
	7. Ratios and proportions	Highly Relevant
	8. Definition and application of shapes' similarity	Highly Relevant
	9. Trigonometrical Relationships	Highly Relevant
Algebra	10. Manipulations of ratios and decimal numbers	Highly Relevant
	11. Properties of square roots and powers	Highly Relevant
	12. Manipulations of trigonometric functions	Highly Relevant
	13. Manipulations of logarithmic functions	Relevant

According to the literature, students seem to have difficulties in terms of visualization and analysis of both geometrical and algebraic structures, as described in table 4.2.2.1. iMuSciCA, providing an engineering environment in which students can experiment with geometrical shapes in a dynamic fashion in order to create musical instruments, aims to provide means to address these difficulties. Furthermore, 3D geometry and its basic rules can be introduced in a playful fashion through

educational scenarios, as the iMuSciCA workbench will provide students with opportunities to interact with such objects, thus enhancing their spatial reasoning.
Algebraic manipulations both simple, such as the manipulation of proportions, and advanced, such as the manipulations of logarithmic and trigonometric functions, can be addressed through students researching the functional dependencies of various parameters in the musical instruments they design.

4.2.3 Student difficulties in Engineering

Engineering is a field which is not introduced systematically in standard K12 curricula as opposed to vocational education, but mainly in an optional fashion throughout project work, student clubs or elective subjects. As a result of this minimal interaction, student misconceptions about engineering principles and the engineering profession in general propagate from the views of their environment and their teachers' attitudes.
In the framework of iMuSciCA, the pedagogical design incorporates the engineering cycle of defining a problem by asking questions, imagining potential solutions, planning the design of a prototype, building the prototype, testing the prototype, assessing and optimizing the results and providing the final product. Furthermore, the iMuSciCA workbench provides the students with ample opportunity to experiment in the design of a final product and comprehend the interrelations between engineering, science and mathematics.

4.2.4 Difficulties in relating Music with Science

There is a general belief nowadays that Music, as it is linked to emotions and personal feelings, could not have any connection whatsoever to Maths or Science which is believed to be objective general, and not connected to 'appreciations' like beauty, aesthetics and personal feelings. However already in ancient times the connection between simple mathematical proportions and musical harmony and consonance, was discovered by the Pythagoreans. By further development of mathematics and physics it became clear that with trigonometric functions sound waves can be modeled and properties like timbre, consonance and dissonance can be further understood. Physicists like Hermann Von Helmholtz and James Jeans wrote in the 19th and 20th century, books on the ever expanding relations between music and science. Especially with the digitalisation of music nowadays it becomes more than ever clear that there are numbers and mathematical patterns behind music that can used to store, to play but also to create music.
So, iMuSciCA, with its envisaged STEAM pedagogy will in this sense create opportunities in classroom for teachers and students to discover these old and new links between music, science and engineering.
iMuSciCA will help to address following links between Music and Science, which are not obvious, sometimes not even to experienced teachers or musicians:

- between simple mathematical proportions and musical intervals
- between natural tones and mathematical proportions
- between natural tones and standing waves
- between melody as a sequence of intervals
- between harmony and the simultaneous sounding of musical intervals
- between the mathematical pattern in the upper tones and the musical consonance and dissonance
- The concept of scale and the relationship of sounds.
- The concepts of musical time, rhythm and mathematical patterns
- Elementary principles of musical composition and the relation with harmonics

- Man and the production of sound in physical, mechanical, and body aspects

The production of sound as a mere human ability on the one hand, and the "synthesis" of an organized set of sounds in time on the other, is determined by the relationship of the human body to what we call an echogenic body (sounding-body). In other words, the coordination of the molecules of the medium as an act that carries energy, determines the relation of mechanics between the human and the sounding-body as well. Through a controlled environment, iMuSciCA is going to study the above interactions by creatively putting students to experiment with the scientific parameters of musical instrument construction. Using advanced hardware actuators, students are actively involved in this process as they physically move to produce the sound of the instrument they design.

- Fundamental aspects of Sectio Canonis and their use in music creation
iMuSciCA will attempt to prepare a smooth path leading to the study of geometrical theorems in a kind of "musical" way. Assuming that the tension of a sounding body is kept stable, then a series of experimental lessons can engage children's interest in "transferring" the data directly from a geometric environment to a constructional one.
Keynote theoretical texts, such as Euclid's "Division of the Canon" upon which some of the proposed iMuSciCA educational scenarios can dramatically contribute to the above purpose. The term “Canon” (“Κανών”) in Greek means the ruler, a device to construct straight lines. To divide the canon is to determine the intervals produced by the moveable bridge in such a way so as to play all the notes of a scale with all intervals adjusted to the ratios deemed theoretically correct.
Students are invited to explore the physical theories implied by the corresponding geometrical proportions and observe the similarities between mathematical ratios and physics derived from the behaviour of the sounding body.
The project’s learning scenarios will attempt to tackle the issue of musical awareness needed to study works like Sectio Canonis that are silent in terms of their projection into physics. “It seems to take it for granted that its readers are as familiar with these observations as they are with the elementary musical data, and that they are capable of drawing the inference for themselves” (Baker 2007).
Creating simple melodic forms can be the key to secure a solid approach to fundamental musical aspects. The idea of putting a set of tones in a row can trigger the development of basic music concepts such as the formation of elementary rhythmic or melodic patterns. From this step forward, creating simple melodic forms can lead to either advanced theories of musical scaling derived from the conclusions of dividing the canon, or more modern approaches related to free forms like musical improvisation. The use of polychords (bichords, trichords, tetrachords, pentachords and so on) is considered as an elementary principle of musical composition and can be adjusted accordingly to the needs and the scope of a collaborating music teacher (please consult “instrument of speech” learning scenario of this present deliverable).

4.3 The proposed iMuSciCA curriculum

4.3.1 Introduction

The iMuSciCA environment provides template scenarios which can act as starting building blocks for lesson scenarios. The modular structure presented in this document allows for further manipulations to create different scenarios and projects. The initial scenarios, and their lesson units, can be combined in order to create altered or even new scenarios and projects.
The content of the basic scenarios is mostly needed to get into the further scenarios. Of course if the students are already familiar with the basic acquired content more advanced scenarios are possible right from the start.
For instance, if you want to go quite direct to “Create your monochord playing *with your own musical scale*” and your students have already a prior experience with waves and sound you could do: 2.2 – 10.1 – 10.2 – 20.1 – 20.2 – 20.3 (see Section 4.2.2). Teachers can create their own lesson plans which they can combine with already existing lesson plans to develop scenarios.

Remarks for correct reading of the outline:

1. Each scenario includes at least two lesson units but typically more.
2. The indicated hours are approximate and can be changed according to chosen methodology (more or less time for self-activities of the students), age group (lower secondary/higher secondary), chosen content…
3. In each iMuSciCA scenario all the fields (of STEAM) are touched. We noted the main fields for each lesson. These are indicative.
4. In each iMuSciCA scenario all the inquiry phases are present. We noted the main inquiry phases after each lesson. These are indicative. Others can occur or the same in a different order.
5. The content of the basic scenarios is mostly needed to get into the further scenarios. The more advanced scenarios are not all interdependent. Many can be done without the other ones. So the teacher can choose between these more advanced scenarios. However, some dependencies are noted with an arrow.
6. iMusciCA is fostering inquiry, collaborative and deeper learning in STEAM. The iMuSciCA workbench and these scenarios and lesson units should be written in this perspective.
7. The generic curriculum refers to 16-year-old students and there is potential for adaptation to higher and lower level students.

4.3.2 The Proposed iMuSciCA Curriculum

Scenario 1: Basics of Waves and Sound *(7 h)*

Lesson Plan 1.1 : -2h- Reminder on waves–M/S – Engage:

Reminder on waves and sound for those with no prior exposure to the subject.

Lesson Plan 1.2: 1h - Sources of music and sound – M/S – Engage/Imagine/Investigate :

Listen to the different families of musical instruments. Investigate which vibration is the source of sound.

Lesson Plan 1.3: 2h - Tone and Noise – M/S – Imagine/Investigate/Analyse/Communicate

Recognizing patterns in waveforms, in time (frequency), in space (wavelength). High tones, Low tones. Measurement of frequency. Amplitude of Sound. Need also to understand the logarithmic scale of music (dB). Use of the iMuSciCA workbench.

Lesson Plan 1.4: 2 h – Communicate basics of waves and sound – M/S/E –Create/Analyse/Communicate:

Students demonstrate the basic characteristics of sound using the iMuscica workbench. Create simple musical instruments and a musical expression.

Scenario 2: Standing Waves and resonant frequencies *(4.5 h)*

Lesson Plan 2.1: 1h – Wave Superposition– M/S – Engage/Imagine/

superposition/interference of waves reflected at the ends of the instrument.

Lesson Plan 2.2: 1.5 h- Standing waves and Fundamental Tone – M/S – Engage/Imagine

Understanding the principle of the formation of a row of standing waves (eigen frequencies). Hypothesizing if this happens with the instruments. Understanding the concept of fundamental tone and natural tones.

Lesson Plan 2.3: 2h – Changing fundamental Tone: changing parameters– M/S/E – Create/Analyse/Communicate

Change frequency of the fundamental by altering boundary conditions (e.g. strings: length, tension, density per length). Investigate some relations using the iMuSciCA workbench.

Can we hear the harmonics separately without changing boundary conditions? Investigate mathematical relation between upper tones/harmonics. Are other resonant tones sounding with the fundamental? Measure a spectrum and verify. Explain why waves of upper tones can exist.

Lesson Plan 2.4: 1-2 h – Communicate findings on resonant waves– M/S/E – Create/Communicate
Students demonstrate findings on harmonics/upper tones using iMuscica workbench. Design simple musical instruments, create musical expression.

Scenario 3: Timbre of musical instruments (5 h)

Lesson Plan 3.1: 1,5 h– Timbre and and upper tones– M/S – Engage/Imagine:

Listen to different instruments playing the same tone. Investigate waveform and spectrum. Discover the mathematical relation between the upper tones in the spectra of different instruments. Students see that an instrument produces a resulting wave as a superpositions of harmonics. Explain why waves of upper tones can exist.

Lesson Plan 3.2: 2h - Timbre and Power Spectra – E/M/S – Imagine/Create/ Analyze:

Investigate mathematical relation between upper tones/harmonics. Are other resonant tones sounding with the fundamental? Students understand timbre and its dependence on harmonics and overtones. Focus on the amplitude of the harmonics. Students work with power spectra of instruments provided by the workbench.

Lesson Plan 3.3: 1,5 h- Connection with musical instruments – M/S – Communicate:

Measure spectra of different instruments and explain why they sound differently even when they play the same tone. Why does the same tone on different instruments has the same pitch but sounds differently? Does the timbre of an instrument changes if you pluck or tap it softer or more firmly? Explain with superposition of waves.

Lesson Plan 3.4: 1-2 h – Communicate findings on resonant waves– M/S/E – Create/Communicate
Students demonstrate findings on harmonics/upper tones using iMuscica workbench. Students explain timbres of instruments or the changes of timbre when you alter the play mode. Make a musical expression with a virtual instrument you created with a specific timbre

Scenario 4: Simple Mathematical proportions and musical intervals (2-4h)

Lesson Plan 4.1- 2h – Consonance of Pythagoras and musical intervals – M/S – Engage/Imagine/Investigate
Investigate on a polychord the relation between the length of strings and the consonance. Find the mathematical proportions. What is the relation with the musical intervals?

Lesson Plan 4.2: 1-2 h – Communicate findings – M/S/E – Create/Communicate
Use the simple mathematical proportions on a monochord (with two strings) to demonstrate consonance/dissonance. Make some simple musical expression with it.

Proposals for f**urther scenarios**

Scenario 10: Musical Scales (4-6 h)

Lesson Plan 10.1 1-2h – Understanding Musical Scales – M/S – Engage/Imagine/Investigate
Listen to different musical scales. Try to find out the mathematical pattern behind a certain musical scale.

Lesson Plan 10.2 1-2h – Create your own musical scale– M/S – Imagine/Investigate/Analyse/Create
Measure the timbre of different instruments. Does the timbre of an instrument change if you pluck or tap it softer or more firmly? Explain.

Lesson Plan 10.3- 2 h – Communicate and make music– M/S/E – Create/Analyse/Communicate
Students explain musical scale and design a virtual instrument that can play their musical scale. Make a musical expression.

Scenario 20: Create your virtual instrument. Make music (4-7 h)

Lesson Plan 20.1- 2h – Choose an instrument, investigate deeper how it makes different sounds – M/S – Engage/Imagine/Investigate
Which parameter do you have to change in order to produce different tones? Look up (or derive) the mathematical relation between the parameter and the frequency.

Lesson Plan 20.2 2-3h – Create the instrument– M/S/E – Imagine/Create/Analyse
Which are the different frequencies of the scale you want to apply on your instrument? Design your instrument.

Lesson Plan 20.3 1-4 h – Communicate and make music– M/S/E – Create/Analyse/Communicate
Students explain how they made the instrument. Create a musical expression in the iMuSciCA instrument performance environment.

Scenario 30: Timbre Revisited (2-3 h)

Lesson Plan 30.1: (1-2h) Timbre of instruments with non-harmonic upper tones - M/S - Engage/Imagine/Investigate/Analyse

Investigate the timbre of instruments with non-harmonic upper tones like membranophones

Lesson Plan 30.2: (1h) Communicate and make music - M/S - *Create/Communicate*

Communicate your findings and make music

Scenario 40: In search of understanding Consonance/Dissonance (4-5 h)

Lesson Plan 40.1- 1-2h – Dissonance of beats– M/S – Imagine/Investigate/Analyse
Listen to dissonance of the beat of two tuning forks. Measure the wave form. Explain as a superposition of waves with slightly different frequencies
Lesson Plan 40.22h – Consonance of Helmholtz– M/S –Investigate/Analyse
Measure the spectra of consonant/dissonant tones. Are there relations between the (upper) tones that can explain cons/dissonance?
Lesson Plan 40.3- 1 h – Communicate and make music– M/S/E – Create/Analyse/Communicate

Students explain Consonance/Dissonance. Make a musical expression with consonance/dissonance.

Scenario 50: Resonant Frequencies Revisited (5-6 h)

Lesson Plan 30.1: (2h) Resonant frequencies of instruments and bodies- M/S - Engage/Imagine/Investigate/Analyse

Investigate the row of eigen frequencies of ideophones, of membranophones but also of objects like a plate, a table, cardboard…. etc. Are these frequencies harmonic or not? One can use a vibrator or actuator that swipes through different frequencies and find the frequencies that make the object resonate (or not).

Lesson Plan 30.2: (2-3h) Change properties in order to change resonant frequencies - M/S - Engage/Imagine/Investigate/Analyse

Change the objects, for instance a cardboard (dimensions, mass distribution, material…) in order to influence the (row of) resonant frequencies. Can you make some resonant frequencies more or less harmonic? Technology like 3D-milling could be used but also simple things like gluing extra cardboards or wooden plates etc. on a body

Lesson Plan 30.2: (1h) Communicate and make music - M/S - *Create/Communicate*

Communicate your findings and make music

Scenario 60: Musical form and geometrical symmetries (3 h)   *Lesson Plan 30.1: (2h) Musical forms and mathematical symmetries M/S - Engage/Imagine/Investigate/Analyse*   *Listen to musical pieces of different form. Which musical forms are there? You see the link with geometrical transformations in mathematics?*   *Lesson Plan 30.2: (1h) Communicate and make music* - M/S - *Create/Communicate*   *Communicate your findings and make music*

These proposed basic scenarios as well as the further scenarios that constitute the "iMuSciCA curriculum" will be discussed and evaluated during the Pilot Testing Phase A, and their final structure and contents will be presented at **D2.6**: "*Intermediate Educational Scenarios and Lesson Plans for iMuSciCA"* (M15).

The aforementioned curriculum structure constitutes a full curriculum that will be able to:

- Effectively tackle the identified student misconceptions and difficulties in the STEAM fields addressed and thus provide the framework for achieving deeper learning of STEM.
- Adapt to the needs of the iMuSciCA involved schools with the flexibility of implementation both in the case of project based education and in the case of regular curriculum interventions.
- Offer the interested educators a full iMuSciCA experience on which they will be able to build and expand both throughout and after the end of the project's duration.

5. The initial iMuSciCA educational scenarios

5.1 Introduction

The initial iMuSciCA educational scenarios constitute a subset of the proposed iMuSciCA curriculum. These scenarios will be implemented and evaluated during Pilot Testing Phase A and aim to demonstrate the iMuSciCA pedagogy and scope as well as the technical integration so far to the participant teachers. These initial scenarios will be updated and enhanced in the 2nd and the 3rd version of this deliverable (D2.6- Intermediate Educational scenarios and lesson plans for iMuSciCA [M15] and D2.8-Final Educational scenarios and lesson plans for iMuSciCA [M18]) where the final structure of the iMuSciCA curriculum will have been developed. For the scope of this deliverable, two initial scenarios have been developed for lower secondary school and two for upper secondary school. These scenarios will be presented and their applicability to the French, Belgian and Greek national curricula will be

discussed. Furthermore, the proposed structure of a 20-hours project consisting of core iMuSciCA scenarios, as well as more specialized variants of scenarios, will be presented. These scenarios will be presented as templates, which summarize the contents of each subsequent phase.

5.2 The templates

The iMuSciCA templates allow teachers to develop their own scenarios both in a brief and in an extended way. A "Synopsis" gives an overview of the IBSE phases that the teacher follows, the field under which this phase is taking place, the duration in terms of school hours along with the description of the objective and the actual activity with its characteristics. The synopsis template hosts a "remarks" column for links or specific guidelines.

The Synopsis

Title:					
Description:					
E: Engineering/Technology, S: Science/Mathematics, M: Music					
Phases	Field	Time	Description	Activity	Remarks

Every line, or a sequence of lines, within the Synopsis may be used as an interchangeable item between different learning scenarios or projects. These items can be adapted or further developed to support individual learning skills and needs.

The detailed template

IMAGINE

Identify relevant variables to investigate – Identify Relevant Solutions to use

Use your imagination and make hypothesis – Choose potential solution

The detailed template allows the teacher to graphically represent and elaborate any detail necessary to support an iMuSciCA lesson plan for each phase such as enlarged screenshots, pictures, diagrams, tables etc. Both templates are used at the discretion of the teachers and they are designed to encourage the communication of ideas and potentials offered by the envisaged workbench.

5.3 iMuSciCA Long Term Projects

The iMuSciCA long term project presented in this section is going to be created for the needs of the iMuSciCA student camp which will take place in Greece in Summer 2018. This serves as an example for the creation of a project. Links in the following document lead to the detailed description when needed.

Title:	**Instruments of speech**		
Keywords:	Monochord, frequency, tension, length, musical patterns, human voice, voice analysis.		
Short Description:	Through the study, analysis and experimentation around the sound properties of their own voice, students create virtual monochords that meet certain requests and measurements. At the end of the training scenario the monochords interpret a series of variations around a melodic sequence.		
Lesson Plans included:	Using theatrical narration to discover pitch deviations in human voice. (6 Lesson Plans) Isolating the characteristic parts of the human voice waveform and	Date:	30/9/2017

	translating them into string vibrations in a virtual instrument. (6 Lesson Plans) Preparing a musical composition and final performance using motifs (sets of notes), (8 Lesson plans)		
Educational Objectives:	Learn the relationship between human voice, frequency, tension and length of a monochord. Explore the similarities between the human voice spectrum and that of an instrument.	Estimated Duration:	20 hrs
Author(s):	P. Stergiopoulos	Age Group:	14-16
Contributor(s):	E. Chaniotakis	Language:	English (Greek translation available also)
Status:	Final	Difficulty Level:	Medium
Dissemination level:	Public	Special Needs Addressed:	No

Title: "Instruments of speech"					
Description: The following scenario is an early investigation for utilizing existing tools (up to 30/06/17) of the iMuSciCA project in the form of an educational scenario. Through the study, analysis and experimentation around the sound properties of their own voice, students create virtual monochords meeting certain requests and measurements. At the end of the training scenario the monochords interpret a series of variations around a melodic sequence.					
Fields: E: Engineering/Technology, S:Science/Mathematics, M: Music					
Phases	Field	Time	Description	Activity	Remarks
Imagine	M	1	Introduction to the peculiarities of the human voice. *-How do we understand that every voice is unique? What are the main features that make the sound of the human voice?*	-Students select a few lines of text (poem or prose). Reading the text as in stage performance, each student observes the spectrum analysis of the voice using the computer microphone and audio analysis applications in real time. -Students observe spectrum analysis of the voice of other students. -Students can record any narration and use it as a reference for each other (students are able to share these recordings / analysis).	The text selected should be quite lively and expressive such as a theatrical dialogue (e.g. https://goo.gl/kTkqbM) It is possible to make references on the "timbre" but at this point the aim is not to analyze in depth the individual characteristics of the human voice. The aim is mainly to observe the phenomenon of continuous change of pitch as we speak.
	M	1	Introduction to the musical melody	-The students choose a smaller text, with equally expressive features and record it	The objective is to observe the differences between the standard (albeit correct)

			Have you ever imagined why while we understand the words and contents of a voicemail or similar app -no matter how perfect it is made- we always realize that it is a machine? *-What are the characteristics that make the human voice, human?*	individually. -Then they copy their text into the google machine translation and record the automatic narrative. -The students collate their own spectroscopic analyzes with those of the automatic narrator.	computer speech and the human speech. Concepts / parameters associated with the Music: Volume, pitch, pauses, rhythm or values (durations). Differentiations between the above parameters in places that are not expected and the fact that that they are not repeated, makes the human version of the narrative natural.
	M	1	Possible extension of previous sessions	Possible extension of previous sessions	Possible extension of previous sessions
Engage	S	1	Introduction to musical instruments *-How can we create sound by putting instruments to creatively imitate the human speech?* *-How the composition of a melody that follows our voice can be reproduced by musical instruments constructed exclusively for this composition?* *-What are those scientific characteristics of sound that will have to study to create these specific musical instruments?*	Version A: Students select one of the texts that have been proposed and work only with it. From this text they select and isolate each word and distribute one for each student. Each student finds the frequency component of the word entrusted. It leads to the frequency with which they will work. Version B: Each student chooses a frequency from the observed spectrum using the analysis of their own narration from the file sampler (http://tesla.ilsp.gr:1994/sampler.1/). Alternative: canvas tool (https://imuscica-platform.unifr.ch/drawme/first/). The melody is recorded and students start to create the instruments that would interpret it.	The objective is to compose a melody made from a sequence of frequencies that each student has proposed. Each student will be responsible for the creation of pitch that he/she has proposed.
	S	1	Introduction to the physics of waves and the sound	teaching of basic concepts that will be then used by digital and non digital-tools.	
	S	1	Introduction to the	teaching of basic concepts that	

			physics of waves and the sound	will be then used by digital and non digital-tools.	
	S	1	Connecting the empirical characteristics of sound with its objective characteristics.	Combination of acquired knowledge in teaching through digital and non-digital tools.	
Create (Investigate / Design)	M,S	1	Manufacture of a digital monochord to play a particular note.	Students construct a digital monochord and experiment with parameters: the chord length, tension across the string to find the optimum parameters for producing a musical note in this instrument. Students collect data.	Students use musical, scientific and technological environment of iMuSciCA to compare the sound that produces the monochord with the sound of the note called upon to produce. By optimizing the parameters of interest from the scientific tab, they repeat the process until completing the production of the instrument. Follow the procedure described in the following lesson plan: https://goo.gl/1D3bRB
	S,E	1	Completion of digital monochord	Completion of digital monochord	Follow the procedure described in the following lesson plan: https://goo.gl/1D3bRB
	S,E	1	Completion of digital monochord	Completion of digital monochord	Follow the procedure described in the following lesson plan: https://goo.gl/1D3bRB
	E	1	Completion of digital monochord	Completion of digital monochord	Follow the procedure described in the following lesson plan: https://goo.gl/1D3bRB
	M,E	1	Repeat the construction procedure for making a virtual monochord that will produce a different note.	Repeat the construction procedure for making a virtual monochord that will produce a different note.	The procedure described in the following lesson plan for different note: https://goo.gl/1D3bRB
	M, E	1	Repeat the construction procedure for making a virtual monochord that will produce a different note.	Repeat the construction procedure for making a virtual monochord that will produce a different note.	The procedure described in the following lesson plan for different note: https://goo.gl/1D3bRB
	M,E	1	Possible extension of previous sessions	Students start to compile the melody/sequence of their monochords. Students can also	The number of notes in the melody and their durations are left to teachers' discretion. They

				design a sequence of variations of the above melody to perform. Possible extension of previous sessions	may vary depending on the number of pupils involved (one for each sound) and the duration of the melody (for example, a melody of 5 seconds for 3-5 notes for students without any musical background is a normal duration for an elementary melodic scheme).
Reflect	S, M	1	Compare and analyse the functional relationship between the frequency of the sound produced and the instrument parameters.	Students use the data collected to find the relationship that governs the frequency of the monochord sound depending on its parameters.	
	S,M	1	Compare and analyse the functional relationship between the frequency of the sound produced and the instrument parameters.	Students use the data collected to find the relationship that governs the frequency of the monochord sound depending on its parameters.	
	S,M	1	Investigation of sound that produces a natural monochord.	Use of FF tools of harmonic analysis.	
	M, S	1	Export conclusions and evaluation	Students present the results of physics produced and evaluated for cognitive strain of their work.	
Commu nicate	M	1	Test of musical instruments, variations of melody, tuning before a presentation. General rehearsal	Students experience what they have created in real musical-praxis environment. Students are aware of concepts concerning rhythm, precision and they cooperate in order to coordinate their interpretation. Prepare presentations about the stages of their project to be displayed in public before the final event. They invite the public and advertise their creation. Students describe the action and post it on the school	The agreed melody is followed by students trying to differentiate its characteristics (change the sequence of notes, their durations, etc.).

				website.	
	M	1	Final presentation / Event	Students perform the event according to the previous session	Public presentation/event

5.4 Scenarios for Lower Secondary School

The scenarios presented in this section have been developed by the UCLL team and are designed for students in the lower secondary school. You will find hereby:

Lower Secondary Scenario 1: **Sound and Tone**

Lesson Plan 1.1: **The sources of Sound**
Lesson Plan 1.2: **What is Tone?**

Lower Secondary Scenario 2: **Standing Waves and Resonant Frequencies**

Lesson Plan 2.1: **The row of resonant tones**
Lesson Plan 2.2: **Resonant tones and standing waves**
Lesson Plan 2.3: **How do standing waves occur?** *(in development)*
Lesson Plan 2.4: Changing the pitch of the fundamental *(in development)*
Lesson Plan 2.5: Design an instrument *(in development)*

5.4.1 Lower Secondary Scenario 1: Sound and Tone

Title:	Lower Secondary Scenario 1: **Sound and Tone**		
Keywords:	periodic, frequency, wavelength, pitch, sound, tone		
Short Description:	iMuSciCA Scenario around basics of sound and tone, aimed at lower secondary		
Lesson Plans included:	Lesson Plan 1.1: **The sources of Sound** Lesson Plan 1.2: **What is Tone?**	Date:	26/08/2017
Educational Objectives:	The following scenario let students inquire: **Lesson 1.1: The sources of Sound** i) how sound and music originates as vibrations (in an elastic medium) ii) how a wave with a fixed frequency is formed on an instrument (that produces a tone of a certain pitch). **Lesson 1.2: What is Tone?** i) Investigate the difference between tone and noise. ii) Explain how the emergence of a wave on a musical instrument is the cause of tone. iv)Design a simple musical instrument that can raise sound and make a musical expression with it.	Estimated Duration:	3-4h
Author(s):	Renaat Frans	Age Group:	Lower Secondary (approx. 12-15)
Contributor(s):	Erica Andreotti, Mieke Schuermans, Jeroen Vanesser, Lander Frans, Jeroen Op den Kelder, P. Stergiopoulos, E.Chaniotakis	Language:	English

Status:	Draft / Final	Difficulty Level:	Lows
Dissemination level:	Public/Custom	Special Needs Addressed:	Yes/No

Lower Secondary Scenario 1: **Sound and Tone - Overview**

Lesson Plan 1.1: **The sources of Sound - Overview**

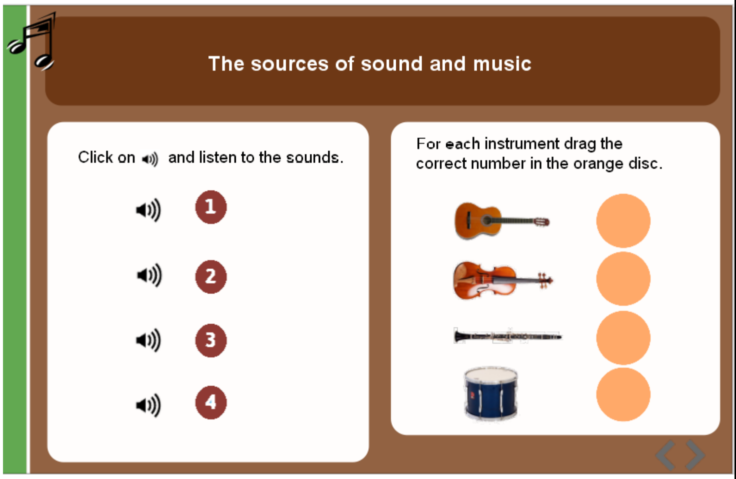
Time	Phases	Field	Description	Activity	Remarks
1	Engage /Imagine	M	Sounds of different instruments are played.	What could be the source of vibration in these instruments? According to 'what is vibrating', one can distinguish at least 4 families of musical instruments.	We start in the musical world.
	Investigate/ Analyse	S	By means of simple experiments: can we observe what is vibrating?	Observe a vibration more carefully: why does the elongation come back every time? Can a sound propagate without making contact? Sound propagates as waves through the air: what does move in a wave?	Our investigation of the sources of sound, continues now in the scientific world.
	Analyse Communi -cate Reflect	S	What did you discover? Discuss and come to conclusions.		
2	Create Design	E/ M	We built simple musical instruments: an aerophone (bottle organ) and an idiophone (bottle bell)	Try to tune the bottle organ and the bottle chimes to notes, so you can play a simple melody on it. With some idiophone, make a rhythm.	Students experience what they have learned about the sources of sound in a real musical-praxis environment. https://goo.gl/1D3bRB

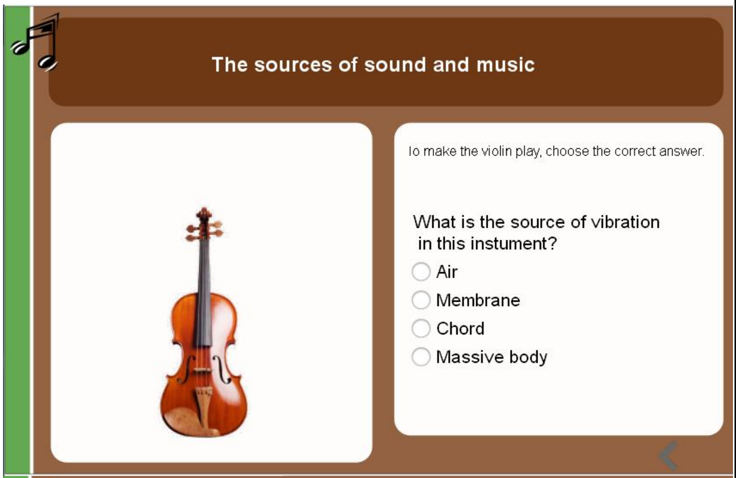
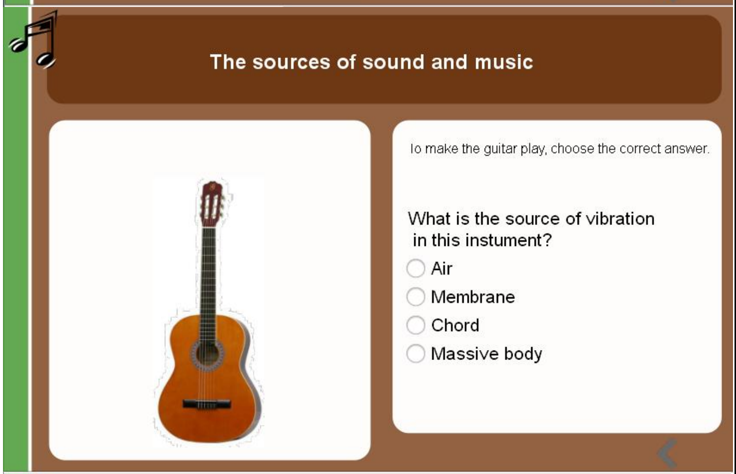
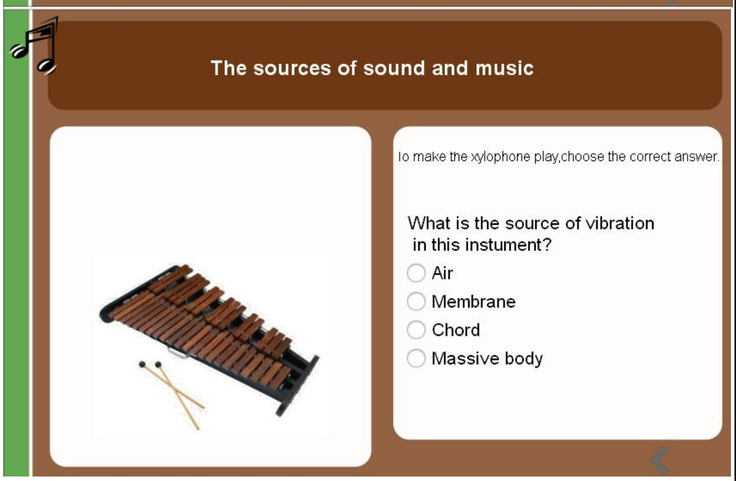
Lesson Plan 1.2: **What is Tone? - Overview**

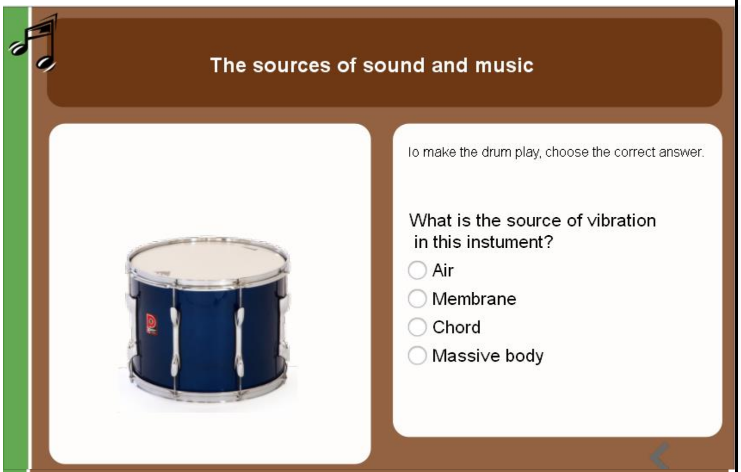
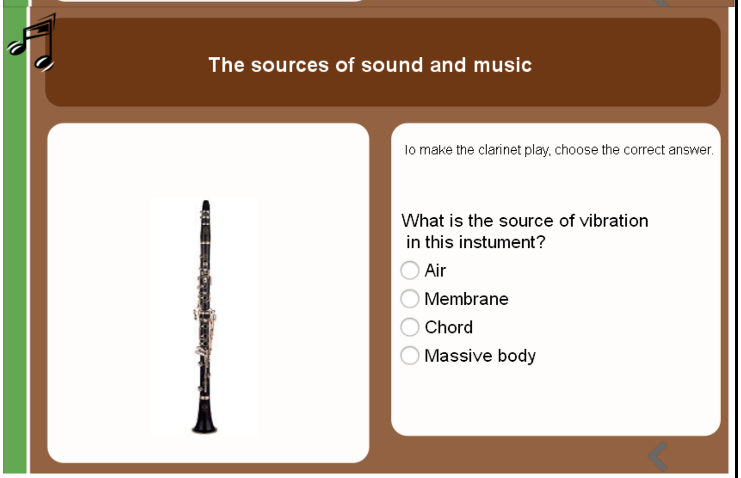
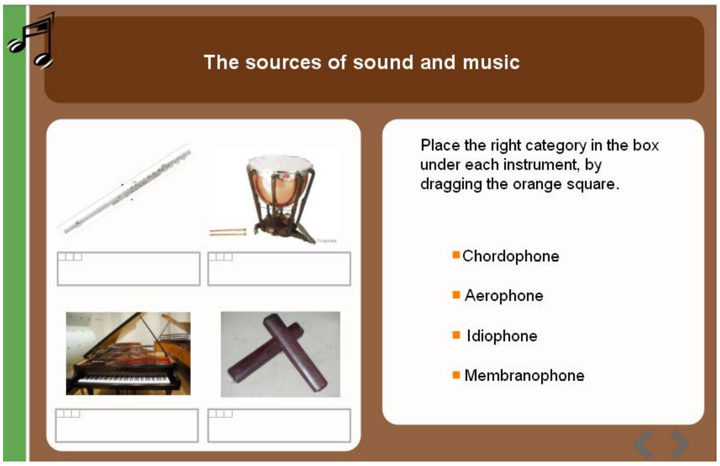
Time	Phases	Field	Description	Activity	Remarks
3	Imagine	S	We measure waveform of different sounds. Which instruments produce a pattern that repeats itself in time and which don't?	Do you recognise a pattern that repeats itself in time? How does a waveform of a low tone differentiates from one of a high tone? Which instruments produce a pattern that repeats itself in time and which don't?	Waveform (in time) is measured on the iMuSciCA workbench. *(VA tool is to be replaced)*
	Investigate	S	The quantity frequency means the number of repetitions. It is measured in units of Hz. This insight is	Measure the waveform precisely in time: Count how often the pattern repeats itself per second a) for a low tone b) for a high tone	Waveform (in time) is measured on the iMuSciCA workbench.

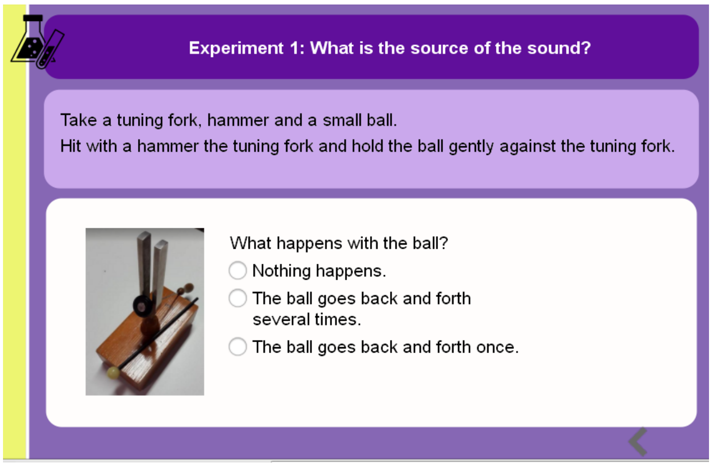
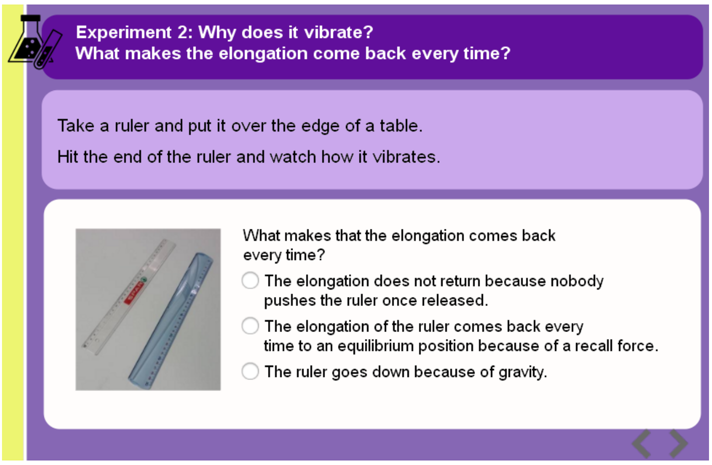
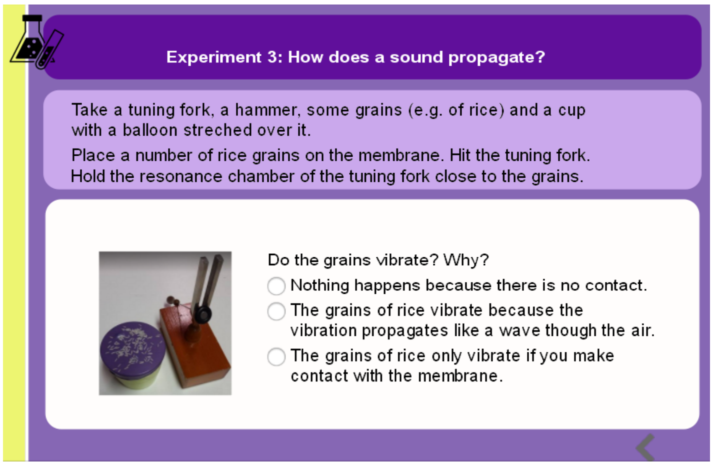
			applied on some notes		
	Analyse	S	The wave pattern *in space* is analysed. It is measured on a model. The quantity wavelength is measured in unit of length.	Students try to recognize the distance over which the pattern repeats itself, now in space (previous it was in time) The distance over which the pattern repeats itself in space is called the wavelength	On the workbench a wave in space is showed.
	Communi-cate Reflect	S	What did you discover? Discuss and come to conclusions.	What is typical for a tone compared to noise? What repeats itself in time? What repeats itself in space?	To be added.
4	Create	M E	In a first musical expression: sound is made with instruments that don't produce much tone. It is done: a) with simple real instruments b) in a digital way by recording sounds of percussions and play them again		Students experience what they have learned in a real musical-praxis environment. This app is accessible from the workbenc.h

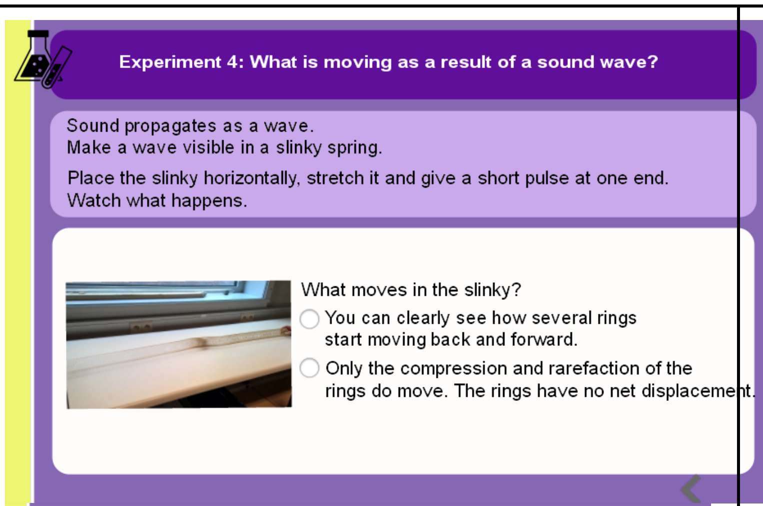
Lesson Plan 1.1: **The sources of Sound - Detail**

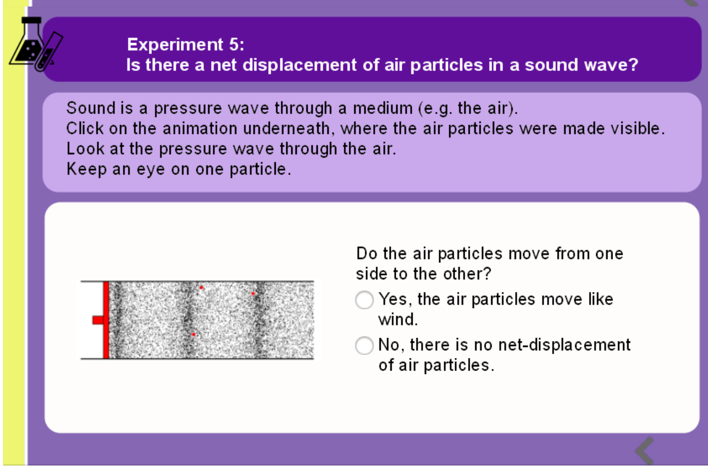
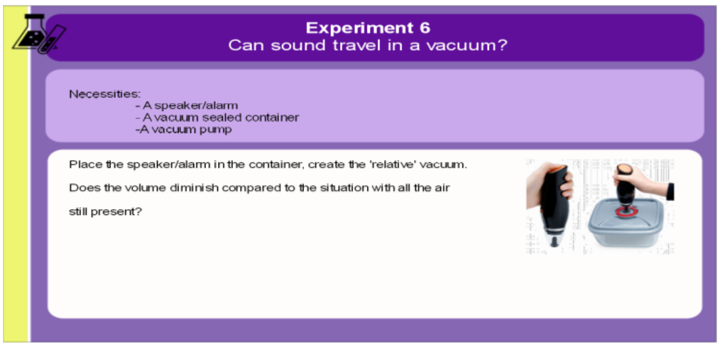
Time	Phases	Field	Description	Activity	Remarks
1	Engage	M	Sounds of different instruments are played.		We start in the musical world.

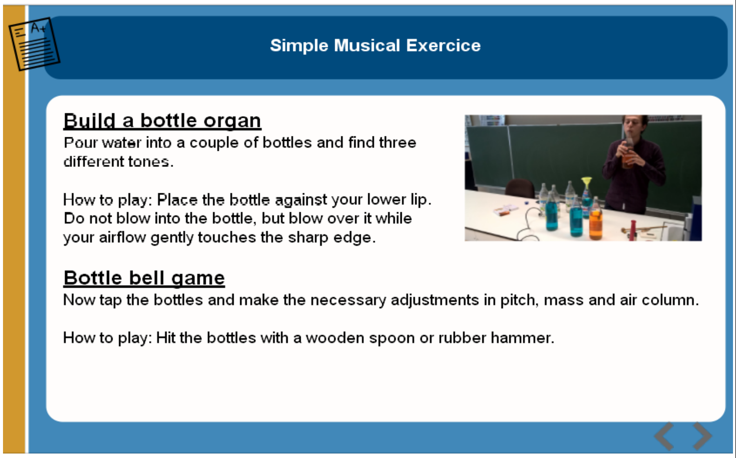
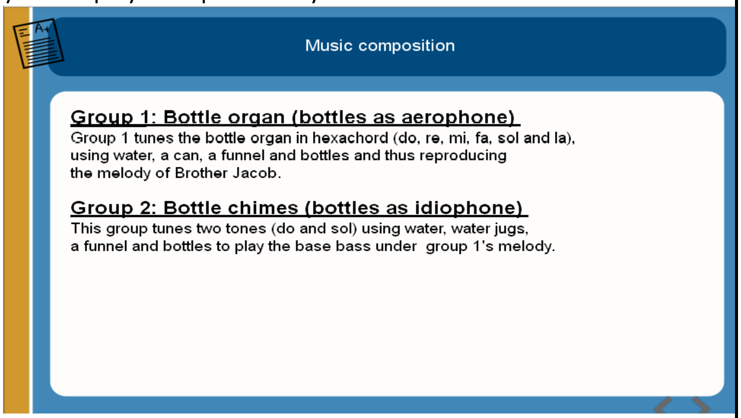
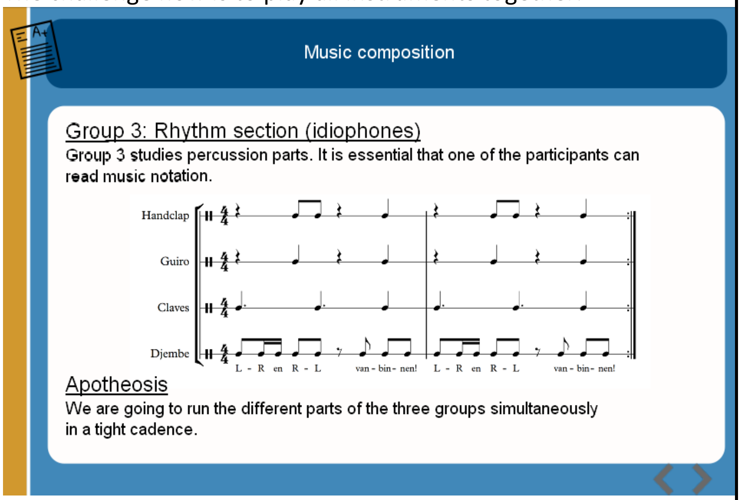
	Imagine / Investigate	M	What could be the source of vibration in these instruments?.		

					
	Analyse	M	According to 'what is vibrating', one can distinguish at least 4 families of musical instruments.		These are our first conclusions in the musical world.

	Investigate	S	By means of simple experiments: can we observe what is vibrating?		Our investigation of the sources of sound, continues now in the scientific world.
	Investigate	S	Observe a vibration more carefully: why does the elongation come back every time?		
	Investigate	S	Can a sound propagate without making contact?		

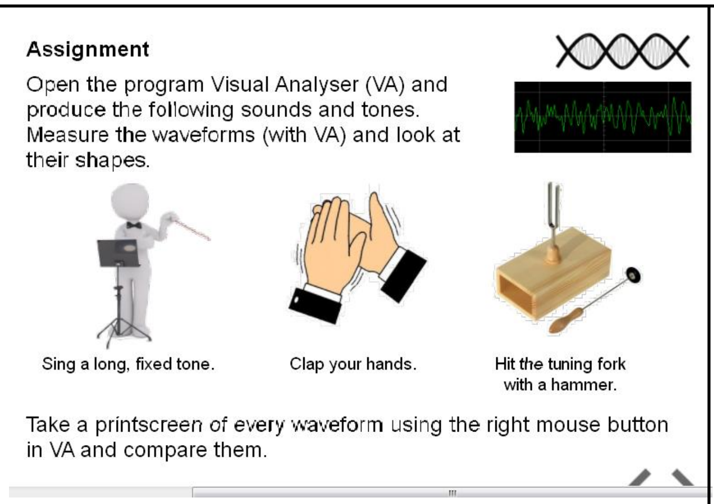
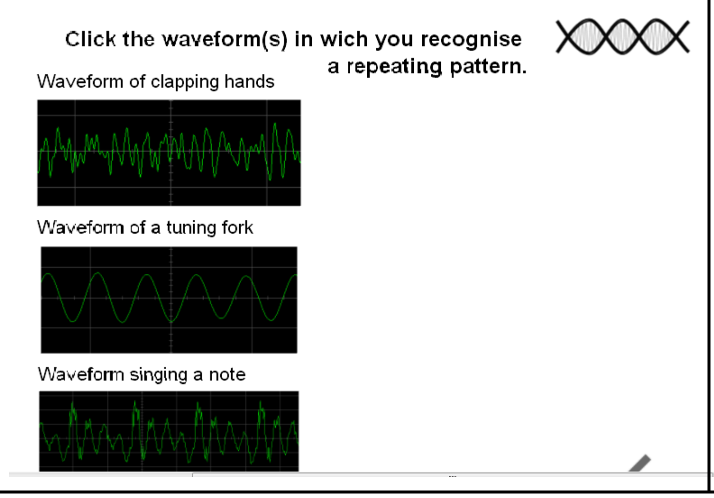
<table>
<tr><td></td><td>Investigate/ Analyse</td><td>S</td><td>Sound propagates as waves through the air: what does move in a wave?</td><td>

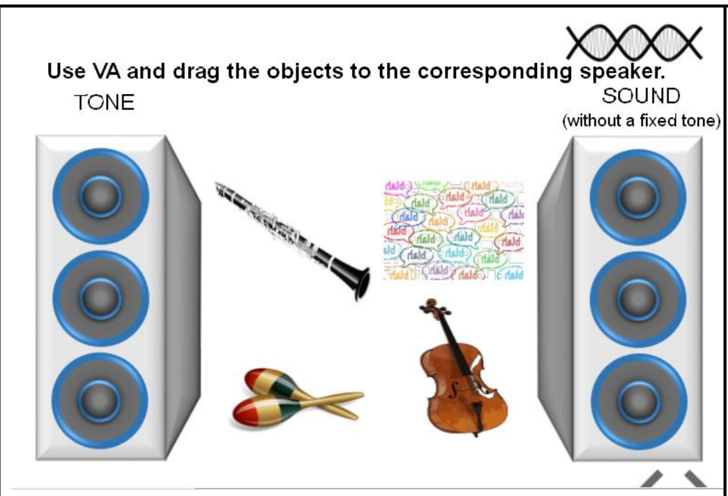

</td><td></td></tr>
<tr><td></td><td>Analyse Communicate Reflect</td><td>S</td><td>What did you discover? Discuss and come to conclusions.</td><td>1. What is always the actual source of a sound, in what does it originates?
2. What vibrates in the 4 different families of instruments?
3. Is it necessary that the vibrating medium is elastic? Why?
4. Through what does the sound propagate until your ear?
5. What this has to do with waves?
6. In a sound wave: do the air particles really move? Or are they just compressed and decompressed?

</td><td></td></tr>
<tr><td></td><td>Create Design</td><td>E/ M</td><td>Students experience what they</td><td>We built simple musical instruments: an aerophone (bottle organ) and an idiophone (bottle bell)</td><td></td></tr>
</table>

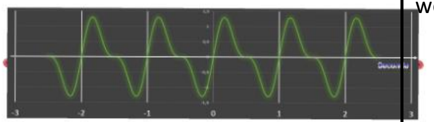
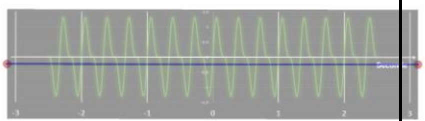
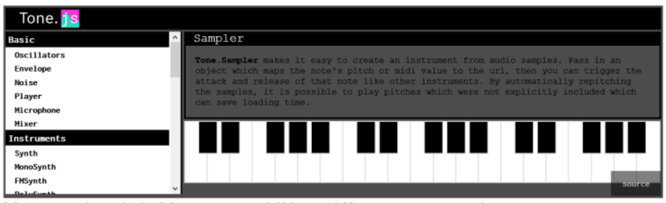
			have learned about the sources of sound in a real musical-praxis environment.		
	Create Design	M		Try to tune the bottle organ and the bottle chimes to notes, so you can play a simple melody on it. 	
	Create Design	M		With some idiophone, make a rhythm. The challenge now is to play all instruments together. 	

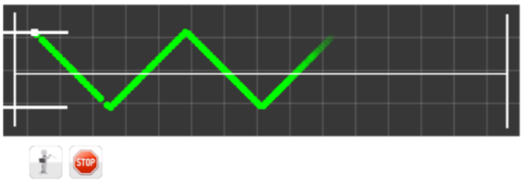
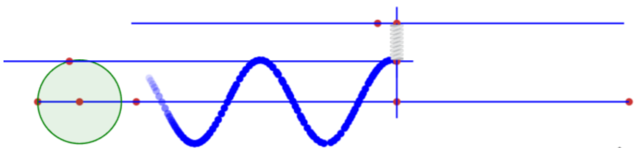
Lesson Plan 1.2: **What is Tone? - Detail**

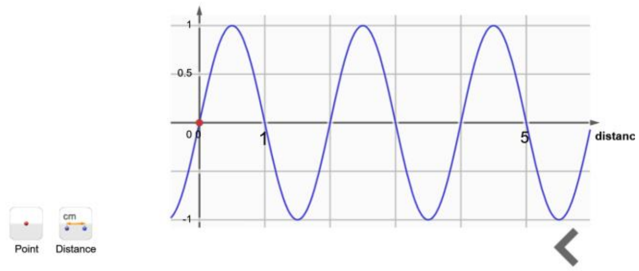
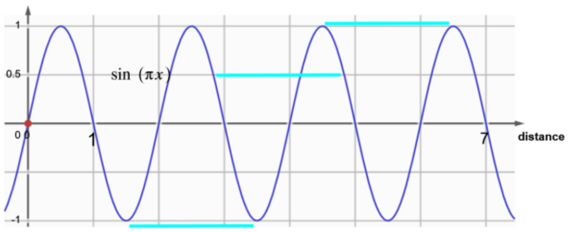
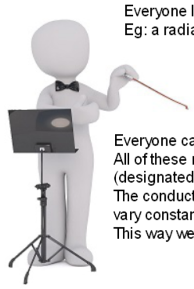
Time	Phases	Field	Description	Activity	Remarks

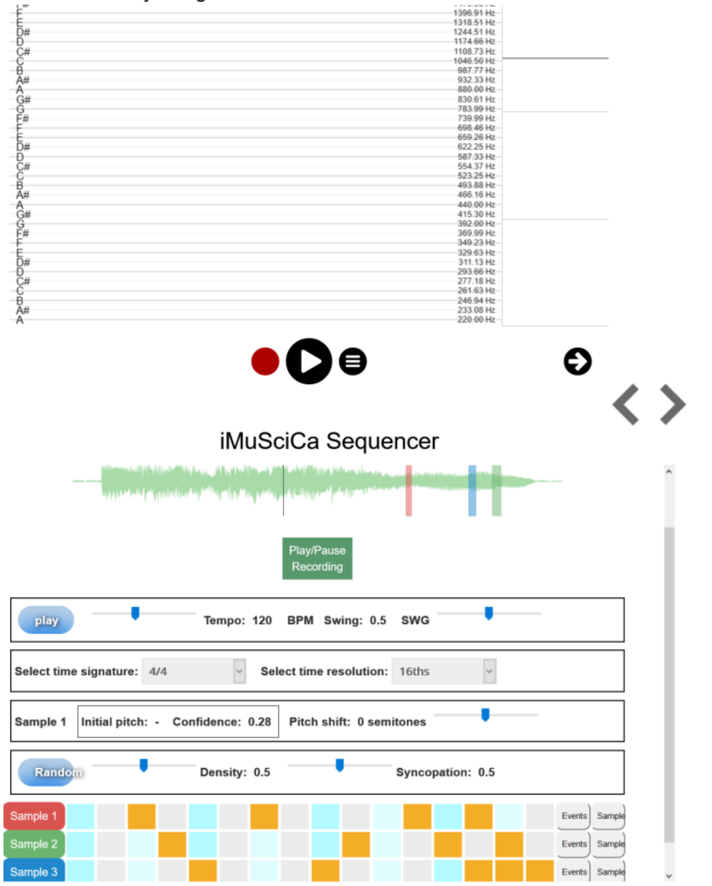
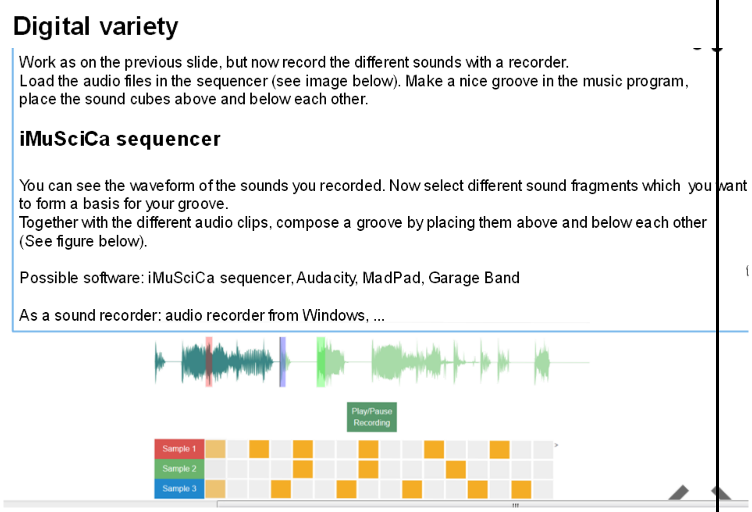
<table>
<tr><td>3</td><td>Imagine</td><td>S</td><td>We look to the waveform of different sounds.</td><td>
</td><td>Waveform (in time) is measured on the iMuSciCA workbench.
(VA tool is to be replaced)</td></tr>
<tr><td></td><td>Investigate</td><td>S</td><td>Do you recognise a pattern that repeats itself in time?</td><td>
</td><td></td></tr>
</table>

<table>
<tr><td></td><td>Investigate</td><td>S</td><td>Which instruments produce a pattern that repeats itself in time and which don't?</td><td>
</td><td>Waveform (in time) is measured on the iMuSciCA workbench.
(VA tool is to be replaced)</td></tr>
</table>

	Investigate	S	How does a waveform of a low tone differentiates from one of a high tone?	Listen to the tones Tone 1: Tone 2: Which of the two tones has the highest pitch? ◯ Tone 1 ◯ Tone 2 Sing a low and a high tone. Play a low and a high tone on a recorder. Measure each waveform using VA. Capture it with a printscreen.  How does the waveform of the low tone differentiate with the one of the high tone? ◯ The high tone's pattern returns faster in time. ◯ The two patterns are the same. ◯ The high tone's pattern returns slower in time.	
	Investigate	S	Measure the waveform precisely in time: Count how often the pattern repeats itself per second for a low tone for a high tone	**Count how often the pattern repeats per second** Low tone /second  High tone ? per seconde 	Waveform (in time) is measured on the iMuSciCA workbench.
	Analyse	S	The quantity frequency means the number of repetitions. It is measured in units of Hz. This insight is applied on some notes.	**Assignment** Play an a' (central la) on a piano or keyboard. For instance with the sampler below.  Measure the pitch. You can use VA's tool 'frequency meter' or you can use Unifri's tool below Pitch a' = ? Hz 	Waveform in time, the frequency is measured on the iMuSciCA workbench.

				Assignment Play an a' (central la) on a piano or keyboard. Measure the pitch using VA's tool 'frequency meter'. The amount of repetitions per second is called the frequency which is expressed in units "Hertz', written as 'Hz'. e.g.: 10 Hz means '10 times per second' Input the measured frequency below. Pitch a' = ? Hz **Assignment** Play a middle C (do) on a piano or keyboard Measure the pitch using VA'. Enter the frequency without decimals. Pitch C (do) = ? Hz		
	Analyse	S	The wave pattern *in space* is analysed. It is measured on a model. The quantity wavelength is measured in unit of length. Students try to recognize the distance over which the pattern repeats itself, now in space (previous it was in time) The distance over which the pattern repeats itself in space is called the wavelength	**Is there a pattern that travels through space as well?** Take a pen and a piece of paper. One student steadily pulls the paper away. Another one moves the pen up and done deviating equally far with each stroke along a vertical perpendicular line. (Hold a fixed position with a constant fequency) . Do you notice a regular pattern in space? Measure the waveform across which the pattern repeats itself. Waveform = cm   In the game "Pong" the ball moves up and down at a constant speed. Press play to see the trajectory. How come the ball bounces at a 90° angle and not with a curve?  What's the difference between this trajectory and the upper one? The air particles move in the latter form.This is called a sine wave.	First it is done on a paper model where students create a wave by vibrating the pencil and they let the wave propagate by moving the paper underneath. On the workbench a wave in space is showed. With a ruler students can measure the wavelength.

				Is there a pattern in space? In the figure you discover the waveform of a tone. Is there a distance whereover the pattern repeats itself? Can you measure this distance? ?  wavelength  There is a pattern that recurs in space. This distance, after which the pattern returns is called the wavelength.	
	Communi-cate Reflect	S	What did you discover? Discuss and come to conclusions.	What is typical for a tone compared to noise? What repeats itself in time? What repeats itself in space?	
	Create	M E	In a first musical expression: sound is made with instruments that don't produce much tone. It is done: with simple real instruments in a digital way by recording sounds of	**Musical Exercice: Make a groove using sound** **Let's circle-groove!** **Live-variety** Everyone looks for a sound-producer in the area (so no tone-producer!). Eg: a radiator, a coat stand, a cup, a lunch box, your own body ...  Click the conductor for an introduction clip. Everyone can create their own rhythm which you must sustain throughout the groove. All of these rhythms are stacked together by a conductor (designated in the group, you can change conductors). The conductor can designate one instrument to play, or a couple to play together and vary constantly. This way we create music only using sound and a groove is created.	Students experience what they have learned in a real musical-praxis environment.

			percussions and play them again	**Musical exercice** Create a melody using the Unifri tool  	This app is accessible from the workbench

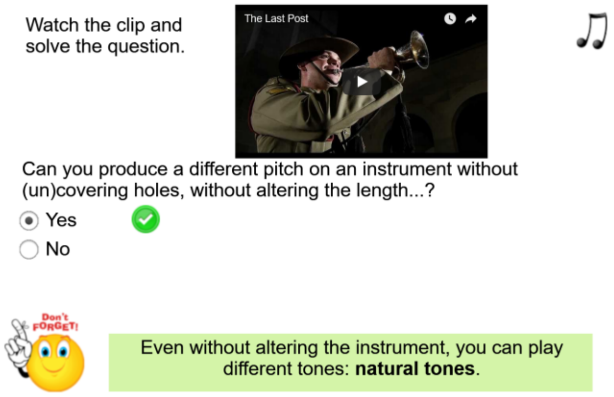
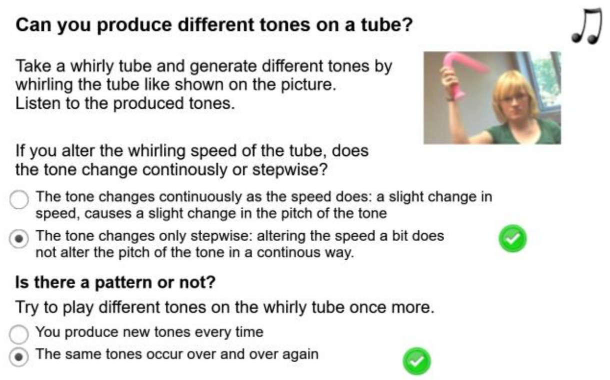
5.4.2 Lower Secondary Scenario 2: Standing Waves and Resonant Frequencies

Title:	Lower Secondary Scenario 2: **Standing Waves and Resonant Frequencies**
Keywords:	eigen frequencies, standing waves, pitch, fundamental, natural tones

Short Description:	iMuSciCA Scenario around natural 'eigen' frequencies of instruments		
Lesson Plans included:	Lesson Plan 2.1: **The row of resonant tones** Lesson Plan 2.2: **Resonant tones and standing waves** Lesson Plan 2.3**: How do standing waves occur?** Lesson Plan 2.4**: Changing the pitch of the fundamental** Lesson Plan 2.5**: Design an instrument**	Date:	27/09/2017
Educational Objectives:	- to recognise the fact that strings and air columns have certain resonant frequencies - to discover a certain row of standing waves that causes these precise resonant frequencies - to discover that altering boundary conditions like length, tension and density, changes the pitch of the fundamental - to apply these insights in designing a simple instrument	Estimated Duration:	4-6 h A minimum programme could be lesson 1, 2 and parts of 4 (only strings)
Author(s):	Renaat Frans	Age Group:	Lower Secondary (approx. 12-15)
Contributor(s):	Erica Andreotti, Mieke Schuermans, Jeroen Vanesser, Lander Frans, Jeroen Op den Kelder, P. Stergiopoulos E.Chaniotakis	Language:	English
Status:	Draft / Final	Difficulty Level:	Low
Dissemination level:	Public/Custom	Special Needs Addressed:	Yes/No

Lesson Plan 2.1: **The row of resonant tones - Detail**

Time	Phases	Field	Description	Activity	Remarks
1	Engage /Imagine	M	When you play an instrument where you don't 'change anything', you can produce a precise series of natural tones.	You listen to the resonant frequencies of a single instruments (natural tones). It is important that you don't change anything: e.g. on a wind instrument you don't open or close any holes, on a string instrument you don't change the tension nor the length of the strings. The only thing you can change is the way you generate the vibration (e.g. blowing harder, striking a string on another place… etc.). **How can you produce different tones on a flute?** How can you alter the pitch on a flute? ◉ By (un)covering the holes. ○ By blowing longer. ○ By holding the flute more to the left side. 	We start in the musical world and listen to the row of resonant frequencies.

				The series of natural tones/eigen frequencies on an Alphorn	
	Investigate/Analyse	S	What are the frequencies of these tones? Is there a relation between the frequencies of resonant tones on an instrument?	We measure the different frequencies of the consecutive natural tones one can play on an instrument where you don't change any boundary condition (don't make tubes or strings longer of shorter, don't alter the tension of strings etc.) Can you produce tones in between without changing any boundary condition of the instrument?  *A whirly tube* One finds that: - the 2nd tone in the row has a frequency that is twice the one of the ground tone. - the 3rd tone has a frequency that is three times the ground tone frequency, etc. So, you can only produce tones forming a discrete series where the frequency of every tone is an integer multiple of the ground tone. Other tones (in between) are not possible. These series of tones are called **natural tones** or harmonics. They are 'own' or 'eigen' (from German word for 'own') frequencies of the string or the tube.	We measure the different frequencies of the consecutive natural tones of a real instrument on the workbench. For instance a whistle or a whirly tube.
	Analyse Communicate Reflect	S	What did you discover? Discuss and come to conclusions.	1. Can you demonstrate the 'eigen' natural tones on aerophone, on a chordophone, on an membranophone? 2. What are the mathematical relations between the frequency of these natural 'eigen' tones?	
	Create Design	M	Can we play a melody only with natural tones?	With the whirling tube or with a whistle a simple melody is formed and played. 	Students experience w hat they have learned about the row of natural tones in a real musical-praxis environment. HYPERLINK "https://docs.google.com/document/d/1wHyqHdlDsOV3_tabcDCj5j18GCqyS8G43rys5lOaE-4/edit?usp=sharing"

Lesson Plan 2.2: Resonant tones and standing waves - Detail

Time	Phases	Field	Description	Activity	Remarks
2	Engage	S	Why you can produce a precise series of natural tones? We try to find the series of waves that are behind these natural tones?	How can it be that the natural resonant frequencies you can play are integer multiples of the ground tone? What are the waves that give rise to these tones? The whirling tube is an aerophone. You can change the tone by speeding up the whirling (because it doesn't have holes like a flute!). Now, let us look at another aerophone: the alphorn. Look how tones are played without changing anything on the instrument (no holes are opened or closed, the length remains unchanged.  **Is there a pattern or not?** ○ You produce new tones every time ◉ The same tones occur over and over again The tones in such a pattern are called 'Natural Tones'.	We pose ourselves some general questions: why?
	Imagine	S	What are the frequencies of these tones? Is there a relation between the frequencies of resonant tones on an instrument?	We continue with the alp horn Which frequency is the lowest pitch 44 Hz The lowest tone in a serie we call the root (chord). Which frequency is the next tone 88 Hz The higher tones are called overtones. All tones combined we call harmonics. What's the frequency of the third harmonic ? Hz C an the frequency of the ground tone change? Can the wavelength of the ground tone change? Can the frequency of the 2nd tone change? Can the wavelength of the 2nd tone change? etc. Listen to the different natural frequencies of the Alpine horn. Find the pattern. Root or first harmonic = 44 Hz Second harmonic = 88 Hz Third harmonic = 132 Hz How do you find the next harmonic using the previous? Complete. Fourth harmonic = 176 Hz Fifth harmonic = 220 Hz Sixth harmonic = 264 Hz	We imagine in the scientific world which possibilities would logically be possible.

Complete the table with the frequencies shown in the alp horn clip. The lowest frequency in row 1, moving up to 5.

n	F (Hz)	Difference (Hz)	Proportion f_n/f_1
1			
2			
3			
4			
5			

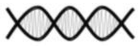
So the waves should be fixed.

Now, produce different tones on a tin whistle without changing anything on the instrument, don't open or close holes, do not alter the length...

Just blow harder or softer.
It is easier to start with all holes closed.

Because the 2nd tone is higher than the 1st, the 3rd is higher than the 2nd, the wavelengths must become shorter every time, the frequencies higher every time.

<u>Can you find the mathematical pattern?</u>



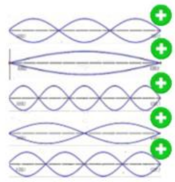
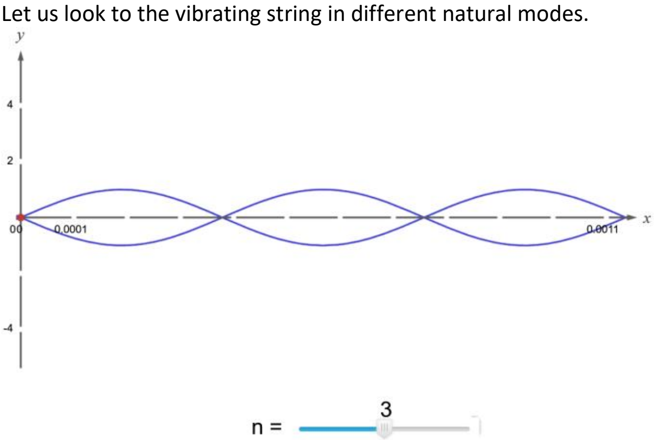
Measure the frequency of different tones playing the tin whistle using visual analyser.

n	F (Hz)	Difference (Hz)	Proportion f_n/f_1
1			
2			
3			
4			
5			

Start with the lowest tone in row 1 and move up.
Note the difference in frequency between every tone.
Make the proportion between the frequency of every tone (fn) and the frequency of the first one (f1).

Conclusion:

Without altering an instrument
(such as adjusting the length, (un)covering holes,...),
you can play different tones.
These follow a precise mathematical pattern.
Those tones are called **natural tones**,
eigen tones or natural frequencies.

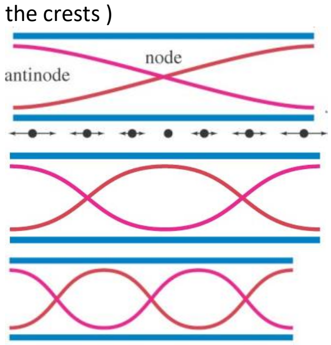
<table>
<tr>
<td></td>
<td>Analyse</td>
<td>S</td>
<td>What will be the mathematical relation between the wavelengths as you the mathematical relation between the frequencies?</td>
<td>
Why do you get such a precise array of natural tones?
As long as you don't alter anything about an instrument, you can only apply a certain array of waves to the length of your instrument. Take for instance a string. Which are possible waves on this string?
Drag the corresponding wave into the right frame
<table>
<tr><th>n</th><th>F (Hz)</th><th>Difference (Hz)</th><th>Proportion f_n/f_1</th></tr>
<tr><td>1</td><td>110</td><td>1</td><td></td></tr>
<tr><td>2</td><td>220</td><td>2</td><td></td></tr>
<tr><td>3</td><td>330</td><td>3</td><td></td></tr>
<tr><td>4</td><td>440</td><td>4</td><td></td></tr>
<tr><td>5</td><td>550</td><td>5</td><td></td></tr>
</table>

Let us look to the vibrating string in different natural modes.


● Draw the waves behind every mode on a string (maximum displacement of air is where the crests are)
1st mode:

2nd mode:

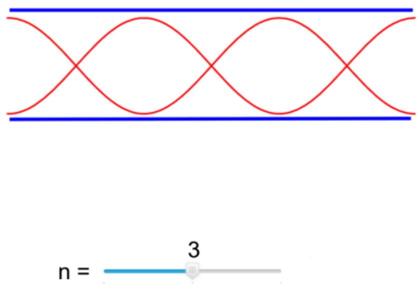
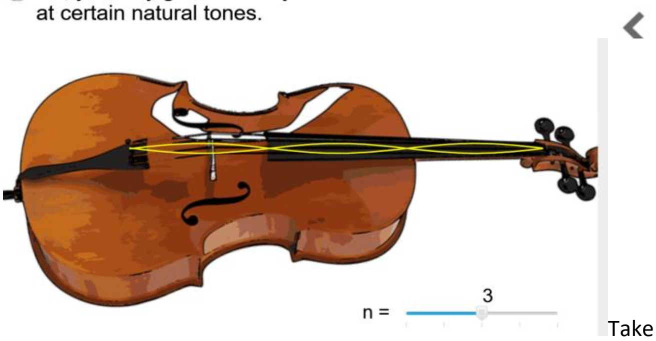
3rd mode:
……….

etc.

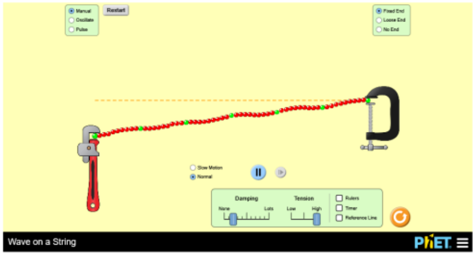
● Draw the waves behind every mode on a tube (both sides open: (maximum displacement of air is at the open ends: there are the crests)


</td>
<td>Our investigation of the sources of sound, continues now in the scientific world.

Possible exercise: Which are the possible standing waves on a half open tube? Draw them.</td>
</tr>
</table>

				Open tubes: test which waves you get with open tubes Use the slider to create different ones  Does the mathematical relation between the wavelengths is still valid?	
	Investigate	S	Can we generate the own 'eigen' vibrations of a string ? Can we determine the different wavelengths of the different own modes?	**Do you get stationary waves with each frequency?**  This series of natural frequencies causes a series of corresponding 'stationary' waves. The nodes and antinodes remain stationary. Attempt to recreate this series of waves using a long spring or rope.  Do you get a stationary wave at each frequency whilst moving up and down? ◯ Yes, you always see stationary waves. ◯ No, you only get stationary waves at certain natural tones.  Take a row (fixed at both ends). Try to make a standing wave of the : - ground tone. - 2nd tone - 3rd tone - etc. By hand: Do you always produce a stable wave?	Do the real experiment AND try this as well on an app e.g. https://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html With the slider (students can look for the 'right' frequencies.

Try to make a standing wave of the following by hand:
- ground tone
- 2nd tone
- 3rd tone



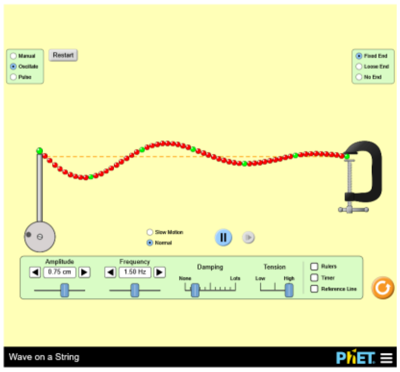
Can you manage to produce a stable wave?

- Sometimes
- Always
- Never

……………….

Depending on the frequency you apply at one end of the cord, you will produce a chaotic movement of the cord that fades away very quickly, or sometimes, when oscillating with the 'right' frequency (one of the 'eigen frequencies of the string), you produce a nice stable wave with a fix frequency.

Only when you have a fixed wavelength, you have a fixed frequency.
Measuring the wavelengths of different modes of a standing wave.
Use the ruler. L is the total length

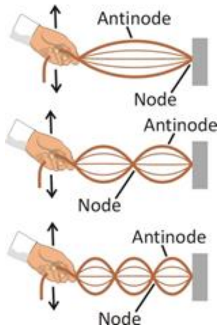
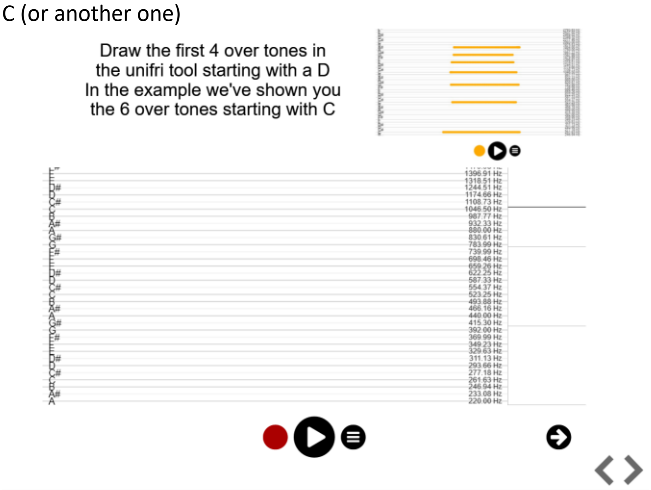


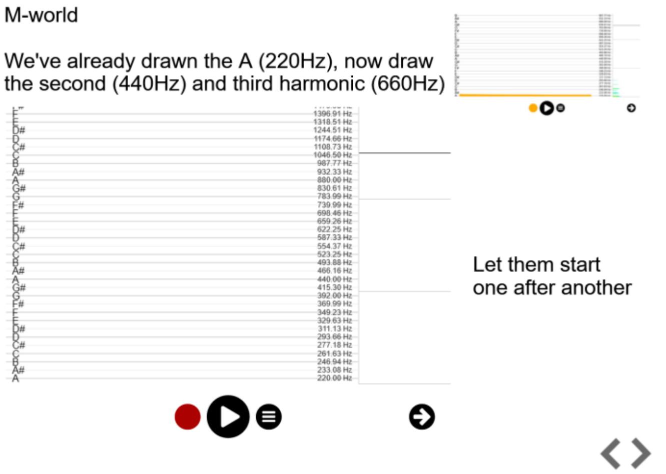
L (m)	mode N	lengte (m)
	1	
	2	
	3	
	4	
	5	

It might be easier by using the semi automatic mode 'oscillate' in the app.

Only when you have a fixed wavelength, you have a fixed frequency.
Measuring the wavelengths of different modes of a standing wave.
Use the ruler. L is the total length.

L (m)	mode N	λ (m)
	1	
	2	
	3	

				4  5 **The 'surviving' waves are the: *standing ones***. They are 'standing' because when you look at them, we get the impression they are not travelling at all. In the Figure you can see the first three standing wave configurations on a cord.	
	Investigate	S/E	Do standing waves occur also on a membrane?	Observe standing waves on a membrane. Make a simple membrane instrument by spanning a balloon or something like that over a little bowl. Strike a tuning fork and come with the wooden resonance chamber of the fork close by the membrane without touching it. What do you see?	A simple membranophone is made.
	Investigate/ Create	M	Make music with different modes on a membrane.	How can you play different modes on a membranophone?	
3	Create	E/M	Create a string/ tube/membranophone instrument with a certain row of natural tones starting at note C (or another one)	Create a virtual instrument on the Workbench with a ground tone in C (or another one)  	Use the iMuSciCA workbench (Design environment) to create a tube/string/membranophone with a certain ground tone.

					
	Analyse Communi-cate Reflect		What did you discover? Discuss and come to conclusions	1. Why are the waves called 'standing'? 2. How are standing waves used in musical instruments? 3. How did you make your instrument with natural tones on C?	

Lesson Plan 2.3: How do standing waves occur? *(under development)*
Lesson Plan 2.4: Changing the pitch of the fundamental *(under development)*
Lesson Plan 2.5: Design an instrument *(under development).*

5.5 Scenarios for Upper Secondary School

The scenarios presented in this section have been developed by EA and are designed for students in the upper secondary school.

Title:	**Let's hear Thales' theorem**		
Keywords:	Monochord, frequency, tension, length, musical patterns, geometrical proportions, Division of the Canon (Sectio Canonis).		
Short Description:	Students use iMuSciCA to divide a string length (or membranophone area) in equal parts keeping tension (and radius in case of string) in constant value and then listen to its different corresponding lengths (or areas). Students perform a composition based on segment divisions and reconstruct their models to achieve same results by altering tension.		
Lesson Plans included:	Understanding the similarities between geometrical segments and musical instruments. (2 Lesson Plans) Dividing the sounding string into parts by following the Thales theorem. (3 Lesson Plans) Achieving the same audio results through altering tension / Experiment with membranophones (3 Lesson plans) Preparing a musical composition and final performance using motifs (sets of notes), (2 Lesson plans)	Date:	30/9/2017

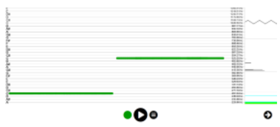
Educational Objectives:	Learn the relationship Sectio Canonis, frequency, tension and length of a monochord. Explore the similiarities between the Pythagorean proportions and tension of an instrument's sounding body.	Estimated Duration:	20 hrs
Author(s):	P. Stergiopoulos	Age Group:	15-17 (14-16)
Contributor(s):		Language:	English
Status:	Final	Difficulty Level:	Medium
Dissemination level:	Public	Special Needs Addressed:	No

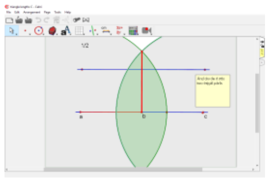
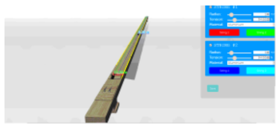
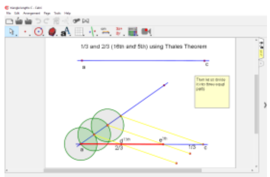
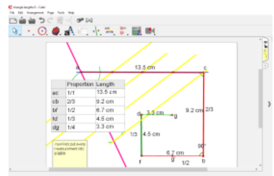
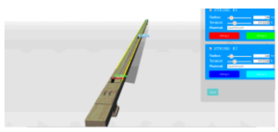
Title: "Let's hear Thales's theorem"

Description: Students use iMuSciCA to divide a string length (or membranophone area) in equal parts keeping tension (and radius in case of string) in constant value and then listen to its different corresponding lengths (or areas). They select a number of string-lengths (or surfaces) to form their own "scale" in a polychord (bichord, trichord, tetrachord, etc.), (or in more than one in case of membranophone). With the help of their music teacher, they use this scale to compose motifs (sets of notes) making brief rhythmical patterns. By altering the tension, students then experiment with new instruments, achieving the same frequencies used in their above scale. They compare their scientific results in table-format and perform the same composition with their new models.

This ten-hours scenario requires that students have their own computer using iMuSciCA platform.

E: Engineering/Technology, S: Science/Mathematics, M: Music

Phases	Field	Time	Description	Activity	Remarks
Imagine	M	1	The musical octave	A music teacher introduces students to the idea of the musical octave using a real instrument (either a guitar, a xylophone, or a flute) Students play on the canvas producing senses of octaves. Teacher encourages students to experiment with octaves in different pitches. Lesson ends with students making a	 Image 1 Drawing canvas for playing octaves Students observe the relation between different pitches starting from different notes

				meaningful sequence of octaves. With the help of their teacher they compose an “octave melody” which is written in music notation. (Each octave is produced by one student)	
Engage	S,M,E	1	Introduction to the segment bisection	Teacher introduces segment bisection. Students study bisection with their own string lengths. They measure the original segment and its half and then produce a bichord using the engineering environment.	 Image 2 Cabri express environment producing bisection  Image 3 3D Instrument Design environment constructing the bichord
Engage	S	1	Thales’ theorem	Teacher recalls the Thales Theorem and asks students to study the division of their own string lengths in 3, 4 and 5 parts. They express each segment in terms of proportions. They measure the lengths of each segment according to these proportions. Results appear on table.	 Image 4 CABRI express environment to produce the division  Image 5 Measurements on a table
Create	S, E	1	Thales’ theorem in bichords A	Teacher introduces the idea of transforming students’ segments into strings (uniform scaling is introduced	 Image 6 – 3D Instrument Design environment is

				at the teacher's discretion) Students apply measurements of segments as string lengths into a bichord.	used to produce the different string lengths. Multiple computers may be used to produce all strings Students use the 3D Instrument Design environment to produce different string lengths. At this stage two computers may be used. Their corresponding String-lengths may be adjusted to agree with each other.
Analyze	S	1	Thales' theorem in bichords B	Students record the sound produced by the monochords and use the EK ATHINA analyzer to observe similarities between different pitches. Teacher helps students to observe relations between string frequencies, proportions and their respective lengths.	Use tables to verify and observe the similarities between different sounds and their acoustical proportion (e.g. if 1/1 is fundamental, then 1/2 should be half the frequency. The same applies for its length.
Communicate	M	1	Thales' theorem in Music using bichords	Music teacher helps students compose the results in a meaningful manner	Using the sequencer teachers select a sequence of notes using combinations of bichords to produce sets. Then they record the results and listen to them.
Imagine	M	1	Can string tensions "play" the same results instead of lengths? Teacher introduces the idea of producing string instruments that have the same pitches with the existing models but	Teacher introduces lengths in a real guitar having the students listen to their proportions (mainly octave). Students experiment with the 3D Instrument Design environment making alternative string lengths resembling their octave in their	Pitches are altered not by string-length but by tension.

			without altering lengths	own models.	
Create	S,E	1	Teacher encourages students to experiment with tension but keeping a "uniform" length. of strings	Students experiment with altering tension and write the results in a table until they match with the existing. Teacher helps students to understand that they need to quadruple (4x) tensions in order to produce octave results	Teacher and students use 3D Instrument Design environment to experiment with different tensions and WIRIS to make calculations. WIRIS environment can be used to produce a graph as well.
Reflect	S, M	1	Building the instruments and preparing for a concert Teacher encourages students to produce a final concert using selections of instruments (with tension and "natural" lengths	Students prepare the instruments built with string tension. Music teacher helps students select different strings in a meaningful musical sequence (sets of notes played by different computers). Students prepare presentations of their work and the final composition.	IRCAM Snail help students observe the differences between the same pitch played with strings in tension and strings played in their "natural lengths" Students experiment and rehearse with the actuators
Communicate	M.S	1	Final Presentation and Concert	Students present their work in groups and then perform their composition	-

Title:	**Scenario A: Investigating a monochord**		
Keywords:	Monochord, frequency, tension, length		
Short Description:	Students will investigate and verify Mersenne's laws on the dependencies of the frequency of the sound produced by a virtual monochord on several parameters.		
Lesson Plans included:	Lesson Plan A1: Learning about monochords Lesson Plan A2: Design a monochord playing Note "A"	Date:	30/9/2017

Educational Objectives:	Learn the relationship between frequency, tension and length of a monochord	Estimated Duration:	7 hrs
Author(s):	E.Chaniotakis (EA)	Age Group:	14-16
Contributor(s):	P. Stergiopoulos (EA), Renaat Frans (UCLL)	Language:	English
Status:	Final	Difficulty Level:	Medium
Dissemination level:	Public	Special Needs Addressed:	No

LESSON PLANS

Title: Lesson Plan A1: Learning about monochords

Description:

In this lesson plan, students will be introduced to the science behind the sound of the monochord. The lesson plan is addressed to High School Students (Age 14-16) with an estimated duration of 2,5 hrs.

E: Engineering/Technology, S: Science/Mathematics, M: Music

Phases	Field	Time	Description	Activity	Remarks
Engage Wonder, Ask Questions, Explore, Observe–Identify Problems, questions and chances	M	0.5 hrs	- Have you ever wondered how do musical instruments sound? - Have you ever wondered why they produce the sounds they produce? - Does the sound produced depend on parameters of the musical instruments? Discuss. This is the image of the largest guitar ever manufactured and achieved the 2017 Guinness Record: It is almost 4m long! Do you think it is playable? If we kept the tuning of a normal guitar, would it produce the same sounds? Assume that this guitar has strings similar to a normal guitar.  - Likewise, listen to the sound produced by a mini-guitar:		

			https://www.youtube.com/watch?v=cvfu5O1lqpU Is the tuning the same with this of a normal guitar? Once again assume that the strings are similar to those of a normal guitar. Let's investigate the science behind these instruments and perhaps we'll break the World Guiness Record!	
Relate to Background Knowledge	S	1 hr	Let's remember some things about sound: 1. What are the fundamental properties of waves? Let's watch the following video and remember https://www.youtube.com/watch?v=TfYCnOvNnFU Discuss: - How are the wavelength, the frequency and the velocity of a wave related? - What is the amplitude of a wave and how does it relate to its energy? - On what does the velocity of a wave depend? - On what does the frequency of a wave depend? - What kinds of waves exist if we take into account the motion of a molecule of the medium compared to the direction of the propagation of the wave? - What happens when two waves meet? 2. Let's remember some key features of sound: https://www.youtube.com/watch?v=qV4lR9EWGlY Discuss: - What are the sources of sound? - What is pitch and what is loudness? - Is sound a transverse or a longitudinal wave? - Which are the frequencies that humans can hear? - How does the mechanism of hearing compare to the mechanism of a microphone? - Does the loudness of a sound depend on the distance from the source of it? Now that we have reviewed our Physics of Waves and Sound, let's see how we can understand the mystery of instrument making!	
Imagine Identify relevant variables to investigate – Identify Relevant Solutions to use	E, S	0.5 hr	The monochord is a string plucked on both of its sides and can be considered as the progenitor of the guitar. It consists of two parts: the body and the string.	

			 Picture 1 As happens with the guitar, likewise, when the monochord is triggered, the string oscillates and produces sound. The frequency of the sound produced is equal to the oscillation frequency of the string. You will be able to interact with the monochord in Musical Instrument Performance environment (http://tesla.ilsp.gr:1994/3dmii.1/) using a Leap Motion sensor. Different ways of triggering the string of the monochord will be available, for example, through a bow or a hammer, whereas, the parameters relevant to the interaction of the user with the monochord will be the interaction point, the distance of the interaction tool to the string etc. Listen to the tuning frequencies of different instruments on the link below: http://onlinetonegenerator.com/tuning.html It seems that different instruments can be tuned to different frequencies. Why is that? Brainstorm and discuss the parameters that you believe are important to determine the frequency of a sound produced by a stringed instrument. You can also perform a literature search. Among the parameters of interest, you should discuss: the length of the string, the string tension, the material of the string and the monochord and the thickness of the string. After you narrow down the most important parameters, write them down on your notebook.	
Use your imagination and make hypothesis – Choose potential solution	E, S	0.5 hr	Create a hypothesis on how you could investigate the dependency of the sound produced by a simple monochord with the parameters you chose at the previous step of your investigation. Assume that you are musical instrument manufacturers. You can divide in groups and “draw” your solution, highlighting the steps you wish to follow. Present your solution in the classroom and discuss.	The teacher needs to guide the students towards the paramete rs and method they will investigat

				e throughout the scenario.

Title: Lesson Plan A2: Design a monochord playing Note "A"					
Description: In this lesson plan, students will use the iMuSciCA workbench to create a simple monochord which will be able to play note "A". They will choose the parameters needed (string length, tension) to create a monochord that plays the requested note. The lesson plan is addressed to High School Students (Age 14-16) with an estimated duration of 4.5 hrs.					
E: Engineering/Technology, S: Science/Mathematics, M: Music					
Phase	**Field**	**Time**	**Description**	**Activity**	**Remarks**
CREATE (Investigate / Design) Plan the Investigation / Design the Prototype	E, S	1 hr	In this activity, you will use the iMuSciCA workbench to try different string lengths and tensions in order to produce note "A". ● Enter the iMuSciCA Workbench and choose the "Engineering Tab". ● Choose the 3D Instrument Design environment and choose "Monochord". ● Now you will have to choose the string you need. From the strings presented, choose a Fender Super 250 L's string (with linear density $\mu = 3.*10^{-4}$ kg/m). ● Return to the Engineering tab main menu. You will see the body and the string of the monochord. ● Observe the weights provided in the environment. ● Place different sets of weights and calculate the value of tension. ● Choose the tension to be equal to 60N. ● Go back to the toolbox and choose the meter-stick. ● Use the meter-stick to determine the length of the string. ● Write these initial values of the length and tension in your notebook. ● Now, shift to the music tab and press "Start". The string will be start to oscillate. ● Hear the sound produced and compare it to the "A" musical Note using your ear. https://www.youtube.com/watch?v=buimPG01gcs ● Do these two sounds match? If not, why? Save the sound you produced. ● Go to the science tab and observe the waveform produced from the string. Press pause and use the ruler to measure the period of the sound produced.		

<table>
<tr>
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Transform the period into frequency using the relationship:
f (Hz)= 1/ T(s).
using a virtual calculator.
● Compare your result with the frequency of Note “A” (440Hz). How do these two numbers compare? Now, you will have to think which parameters affect the sound that you hear. Write them down in your notebook.
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<td></td>
</tr>
<tr>
<td>Carry out Investigation / Build the Prototype</td>
<td></td>
<td>1 hr</td>
<td>
● In the course of this activity, you will be changing the length of the string and its tension. The length can be changed by going back to the chordophone option: monochord and you choose a string of the same material with different length.
● Applying the same tension as you did before, 60N, change the length of the string.
● Go back to the music tab and hear the sound produced and then go back to the science tab to measure the frequency of the sound.
● Repeat the process for 6 different lengths: 0.25 m, 0.5m, 0.75m, 1m, 1.25 m, 1.5m.
For each string length, write down the frequency that you measure and save the sound you produced.
<table>
<tr><th>String Tension (N)</th><th>String Length (m)</th><th>Sound Frequency (Hz)</th></tr>
<tr><td>60</td><td>0.25</td><td></td></tr>
<tr><td></td><td>0.5</td><td></td></tr>
<tr><td></td><td>0.75</td><td></td></tr>
<tr><td></td><td>1</td><td></td></tr>
<tr><td></td><td>1.25</td><td></td></tr>
<tr><td></td><td>1.5</td><td></td></tr>
</table>
● Now, reverse the process:
Go back to the engineering tab and choose a string of length equal to 1 m.
Now start changing the tension:
Start from Tension value = 60 N and start increasing it by 20 N in every iteration.
● For each value of the tension, “trigger fundamental harmonic” and hear the sound in the music tab. Compare it with the “A” note.
Go to the science tab and measure the sound frequency.
Repeat the process until you hear note A.
● Write down your results
<table>
<tr><th>String Tension (N)</th><th>String Length (m)</th><th>Sound Frequency (Hz)</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
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</table>
Write down the two sets of values on which the “A” note is produced. Once you are finished, save your instrument.
<table>
<tr><th>Note A (440 Hz)</th><th>String Length (m)</th><th>String Tension (N)</th></tr>
<tr><td></td><td></td><td>60</td></tr>
<tr><td></td><td>1</td><td></td></tr>
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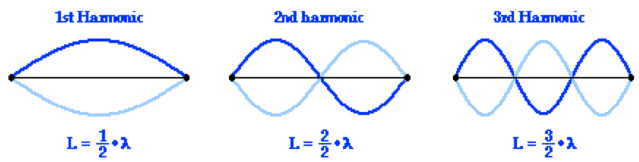
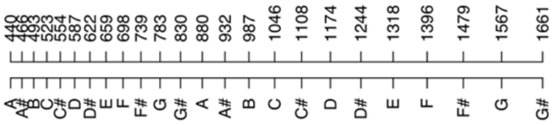
</table>

Analyze Analyze Data from Investigations and Draw Conclusions/ Evaluate the Prototype.	S	1 hr	- Using the data of the two tables you produced, plot the sound fundamental tone frequency with respect to: Tension and length of the string. - Fit the data points with an appropriate function - Make sure that your results are clearly noted and that the axes are appropriately labeled with the correct variable names and units. - Write the dependency of the sound frequency to tension and string length.	
Explain by Relating to Background Knowledge/ Optimize the prototype	S, M	0.5 hrs	Explain your results following the following points: - First watch this video and consider the following questions https://www.youtube.com/watch?v=XDsk6tZX55g - What is a standing wave? - How do musical notes correspond to the frequencies of standing waves? - What are the three categories of musical instruments? - What is the fundamental frequency and what are the upper harmonics? - What is the connection between the sound frequency and the vibration frequency of the string? (They are the same. The sound is a wave produced by a vibrating source: the string. The wave's frequency is equal to the sounding body's frequency). - You see that sound frequency is inversely proportional to the length of the string. Why is that? (Because string length is proportional to the wavelength of the waves created on the string and frequency is inversely proportional to wavelength) You see that the sound frequency is proportional to the square root of tension of the string. Why is that? (The frequency of the sound wave is equal to the string vibration frequency. The string vibration frequency is proportional to the velocity of waves on the string which is proportional to the square root of tension.) In a stringed instrument like a monochord, both ends are plucked. Neither of them can move. As a result, when the string is triggered, a standing wave will be produced. The number of nodes on the string depends on the excitation energy. The lowest energy configuration is this with no node between its ends.  In this exercise, you had to produce Note "A" using the 1st	

			harmonic. The parameters of interest were: String Length “L” (m), String Tension “T” (N) , String linear density “μ” (kg/m). For the first harmonic, L = λ/2. The equation connecting frequency, wavelength and wave velocity is: f = u/2L (1) The velocity of a wave propagating on a string is $u = \sqrt{\frac{T}{\mu}}$ (2). Thus, the frequency of the sound produced is: $f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$ (3) Typical values of guitar string densities are of the order: $3*10^{-4}$ N/m , with string tensions of the order 60 N. If we replace these numbers in equation (3) and solve for Note “A”, the length of the string needed to produce note “A” as its fundamental note is L = 0,5m. Equation (3) describes Mersenne’s law on the sound frequency produced by a monochord. Are your results on par with this law?	
Describe and explain the results in the different STEAM-fields and the connections between them.	S, E, M	0.5 hrs	- How would the monochord sound if you progressively increased the length of the string? Would the pitch increase or decrease? - If you wanted to play note G, would you have to increase or decrease the length of the string while keeping the tension constant? - Is the use of weights efficient in terms of a playable musical instrument? - Propose other ways to vary the tension of the string. - You are asked to create an orthogonal harp with 4 similar strings with equal length: the first string should have note A as fundamental, the second should be an octave higher, the third two octaves higher and the fourth five octaves higher. Which parameter would you vary and how?	
Communicate/ Reflect Communicate Results and Conclusions/ Communicate the Product, perform	S, E, M	0.5 hrs	- Make a short powerpoint presentation using screenshots of the instrument you designed, the waveforms produced and the frequency-tension and frequency-string length plots you created. - Present your findings to your teacher and classmates. Accompany the plots with the saved records of the sounds you produced. - During your investigation, you produced a 440Hz sound in two ways: by fixing the tension and varying the string length and vice versa. Play these two sounds simultaneously. Do you observe consonance? - Discuss with your classmates and ask for their feedback	

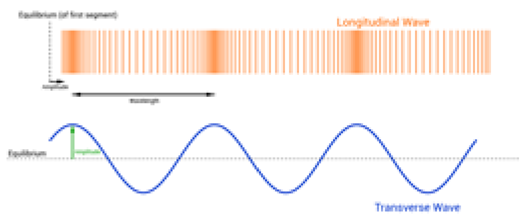
Reflect on Feedback and incorporate in further process	S, E, M	0.5 hrs	- Reflect on the feedback you obtained. - Watch this video of a monochord sonometer and compare with the process you followed: https://www.youtube.com/watch?v=IPH4W3n0t4o - Run through your experiment again. Compare the procedure you followed with the procedure you designed during your “Imagine” phase. Determine the steps you need to take in order to create different monochords with the following frequencies as their fundamental harmonics:  - What is more time consuming, changing the length or the tension of the strings? Relate your opinion to the real world monochords and other stringed instruments.	

Title:	**Scenario B: Timbre and power spectra**		
Keywords:	Timbre, Power spectrum		
Short Description:	Students will experiment and understand why different instruments sound differently. They will analyze different sounds and comprehend power spectra. It is a continuation of scenario A: “Investigating a monochord”.		
Lesson Plans included:	Lesson Plan 1: Timbre and power spectra Lesson Plan 2: Investigating the harmonic content of a monochord	Date:	30/9/2017
Educational Objectives:	- Learn about timbre and why instruments sound differently - Learn what is a power spectrum and how it is manipulated	Estimated Duration:	12 hrs
Author(s):	E. Chaniotakis	Age Group:	14-16/16-18
Contributor(s):		Language:	English
Status:	Final	Difficulty Level:	Medium
Dissemination level:	Public	Special Needs Addressed:	No

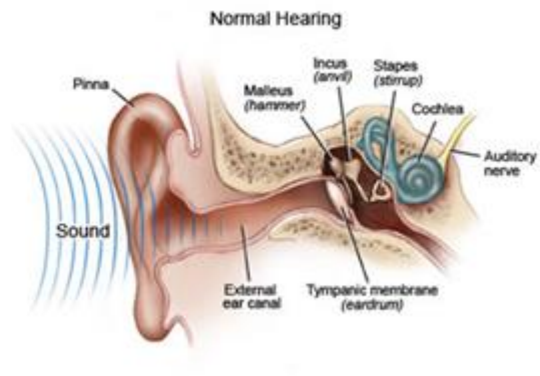
LESSON PLANS

Title: Lesson Plan B1: Timbre and power spectra					
Description: In this lesson plan, students will be introduced to the timbre of musical instruments and investigate the use of the waveform, the power spectrum and the spectrogram. The lesson plan is designed for High School students and has a duration of 4 hrs.					
E: Engineering/ Technology, S: Science/Mathematics, M: Music					
Phases	**Field**	**Time**	**Description**	**Activity**	**Remarks**
Engage Wonder, Ask Question s, Explore, Observe–Identify Problems , questions and chances	M	0.5 hrs	Have you ever wondered why different instruments sound differently? Why do humans' voices sound differently? As we know, musical instruments can be categorised in three families: the stringed instruments, the percussive instruments and the wind instruments. What do you think? Would the same note sound differently for different instruments? Listen to the same note played by different instruments and try to identify differences. The sounds come from the McGill University Master Samples with each of the instruments presented being recorded in studio: https://www.ee.columbia.edu/~dpwe/sounds/instruments/ What do you believe? Do instruments belong in the same family sound differently?		
			Let's find out! Watch the following videos of playing the same song with three different stringed instruments: cello, guitar and violin. Cello:  https://www.youtube.com/watch?v=zdzYFHLHYAI Classical Guitar:		

			 https://www.youtube.com/watch?v=klKn2AmRnWU Violin:  https://www.youtube.com/watch?v=KKVMxvFS5Qo Try to listen to the three instruments in parallel. Can you tell them apart? (https://www.youtube.com/watch?v=sH0q7IWHMA0) How would you describe the sounds that you hear? Which one seems to have a higher pitch? Which seems to have lower pitch? Discuss the differences you spot with respect to the components of the instruments, their size or the way they are triggered.	
Relate to Background Knowledge	S, M	0.5 hrs	Music is defined as vocal or instrumental sounds (or both) combined in such a way as to produce beauty of form, harmony, and expression of emotion. In music, *timbre* is the perceived sound quality of a musical note, sound or tone. The difference in the sound produced by a violin, a guitar and a cello can be identified as a difference in the timbre of the instruments. This difference derives from the different structure of the instruments and the different triggering mechanisms. In order to understand the timbre of musical instruments in a scientific basis, we need to remember that music derives from sound and sound is a wave. - Let us review the fundamental physics behind music: https://www.youtube.com/watch?v=XDsk6tZX55g *Discuss the following questions* -How do musical notes correspond to the frequencies of standing waves? -What is the fundamental frequency and what are the upper harmonics? - How do the frequency and the wavelength of a sound wave relate?	

			-Compare the note G5 as it is produced by a tone generator and a violin: http://www.szynalski.com/tone-generator/ https://www.ee.columbia.edu/~dpwe/sounds/instruments/violin-G5.wav Can you spot any difference? The sound of the tone generator is “monochromatic”: it consists of a single frequency. Could you say the same for the sound produced by the violin: Is it monochromatic or it has overtones?	
Imagine Identify relevant variables to investigate – Identify Relevant Solutions to use	S	1 hr	In order to investigate the composition of the sound of a musical instrument and the correspondence of timbre to the harmonic structure of the sound waves produced, we need analysis tools which will facilitate our research. The tools in question are: - *The waveform analyzer* See the picture below for the comparison of a transverse and a longitudinal wave with single frequency:  Picture 1 Sine waves of a single frequency, thus addressed as monochromatic, obey the equation: **$y = A \sin[2\pi(t/T - x/\lambda)]$ (1)** A: amplitude of the wave (measured in m) T: period of the wave (measured in sec) is equal to 1/f f: frequency of the wave (measured in Hz) λ: wavelength of the wave (measured in m) The detection of sound waves is done by devices located at fixed points in space, therefore the x variable is a constant. Imagine that we place our ear at a specific point in the path of the longitudinal wave of picture 1. As a result, equation (1) can be written as: **$y = A \sin[2\pi(t/T) - \phi]$ (2)** ϕ: the phase, measured in radians, is a constant	

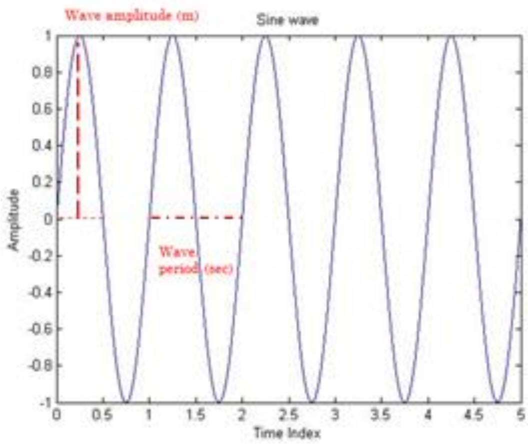
Equation (2) measures the displacement of our 'detector' with respect to time, resulting from a monochromatic wave reaching it. If the wave is a sound wave and the detector is the human ear, then displacement, y, is defined as the displacement of the tympanic membrane.



Picture 2

The plot of equation (2), measuring the displacement of a point in space (y-axis) due to a travelling wave versus time (x-axis), is called the waveform. Waveforms can be displayed through an oscilloscope.

Observe the waveform of a pure sine wave as described in equation 2. Familiarize yourselves with it.



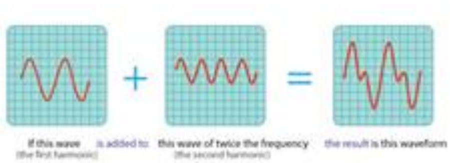
Picture 3

Imagine that you place two sources of monochromatic sine waves with different frequencies at a distance from a microphone. The first source produces a sound of frequency f_1 and the second produces a sound of frequency $f_2 = 2f_1$, its first harmonic. The microphone utilizes a membrane which is forced to oscillate as the sound waves interact with it. This oscillation is transformed into an electric signal which can be sent to an oscilloscope for waveform visualization.

The equation displaying the displacement of the microphone with respect to time will be:

$$\mathbf{y = y_1+y_2}$$

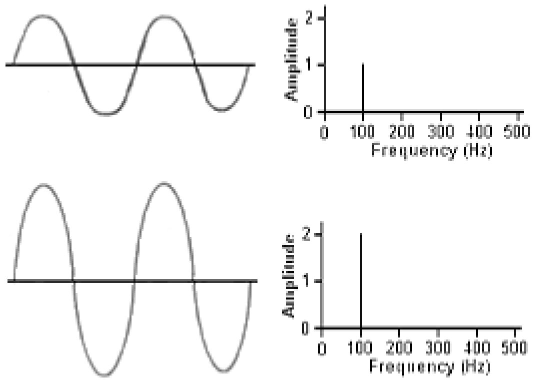
$$\mathbf{y = A_1\sin[2\pi(t/T_1)-\phi_1]+ A_2\sin[2\pi(t/T_2)-\phi_2]}$$

			y: total displacement y1: displacement due to wave 1. y2: displacement due to wave 2.  Picture 4 Let's assume that we want to produce a triangular waveform. How is this done? We add a sine wave, with its third harmonic which has $1/9^{th}$ of the initial amplitude and its fifth harmonic which has $1/25^{th}$ of the initial amplitude and continue with odd numbered harmonics with decreasing amplitudes. In picture 5 you will see an approximate triangular waveform produced by the fundamental tone and its 3^{rd} and 5^{th} harmonic:  Picture 5 ***As a result, we understand that:*** *Any periodic wave with some frequency f can be synthesized from sine waves with the frequency f and its harmonics with amplitudes and phases determined by the shape of the complex wave. This statement is known as Fourier's theorem.* - *The power spectrum* In picture 5 we saw that to approximate a triagonal waveform, we can add the fundamental tone with amplitude A_1, the third harmonic with $A_3=A_1/9$ and the fifth harmonic with amplitude $A_5=A_1/25$. The total power (Power = Energy/Time) of the wave scales with energy, and energy scales with A^2. As a result, the fundamental tone contributes the most to the total power transferred by the wave, while the contribution of the 3^{rd} harmonic is 81 times smaller and the contribution of the 5^{th} harmonic to the total power is 625 times smaller. A histogram called: "Frequency Spectrum", "Power Spectrum" or "Fourier Spectrum" is useful in order to display the harmonic component of a complex wave. The wave shape determines the	

power spectrum, but due to lack of phase information, the power spectrum cannot be used to synthesize the original wave shape.

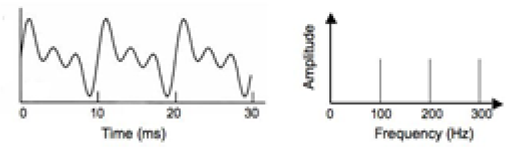
In the following picture, you can see the frequency spectra of two sine waves with frequencies equal to 100 Hz. The second wave has amplitude twice as high as the first.

The y-axis of the frequency spectrum can demonstrate the amplitude, the power, the pressure and other relevant variables whereas the x-axis displays the frequency.



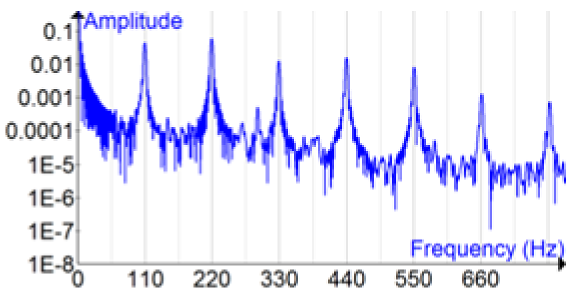
Picture 6

Observe picture 7 to see the power spectrum of a more complex waveform:



Picture 7

The spectra of real world everyday sounds can be analyzed in thousands of waves of different amplitudes, frequencies and phases. As a result, the power spectrum will be continuous with distinct peaks featuring the most prominent frequencies of the sound. You can see such a spectrum in picture 8.



Picture 8

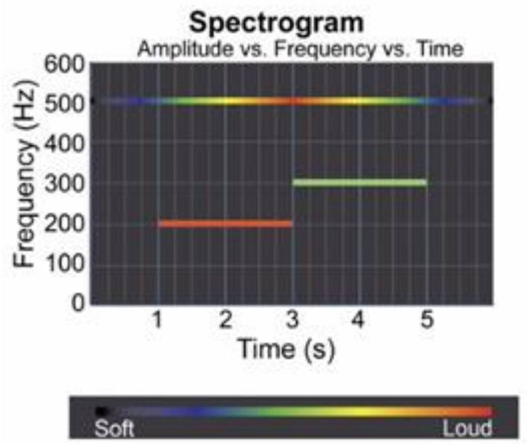
Compare the amplitude of the 110 Hz frequency and the 550 Hz frequency. What is their relationship?

- The spectrogram

Assume that you observe a complex waveform, such as the waveform of an earthquake.

The frequencies of which the waveform consists may contribute in different proportions over time. In order to visualize this attribute, we use the spectrogram. The spectrogram shows both frequency and amplitude with respect to time. A spectrogram is essentially a 3D plot:

It is a graph with x-axis representing time, y-axis representing frequency and the z-axis representing amplitude. Usually, the z-axis is replaced by a color code.

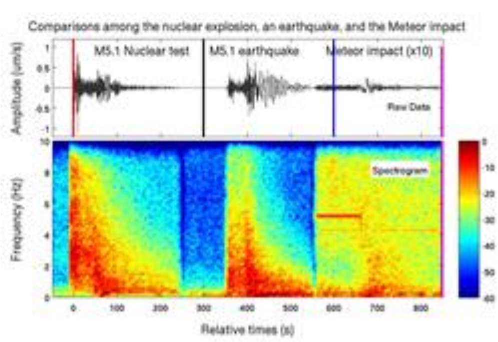


Picture 9

Picture 9 shows the spectrogram of a sound consisting of three frequencies. Can you say which frequency sounds the loudest at t=2s? At which time does frequency equal to 500 Hz sound louder than the others?

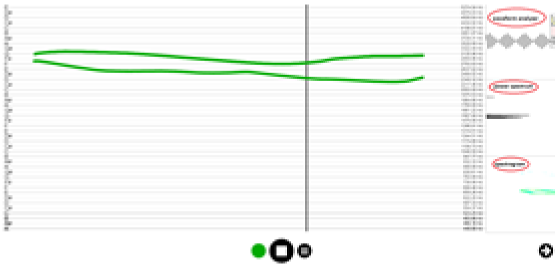
A spectrogram can be produced not only for sound waves, but by any kind of vibration. Such vibrations could be for example the oscillations of the ground resulting from an earthquake, a nuclear explosion or a meteor impact.

Observe picture 10 and see the waveforms and the spectrograms of these three events. What are your comments?

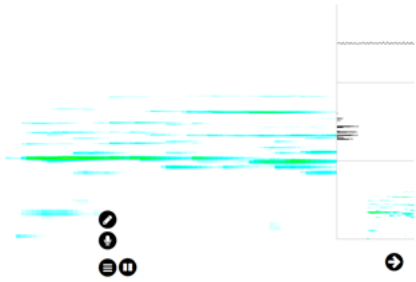


Picture 10

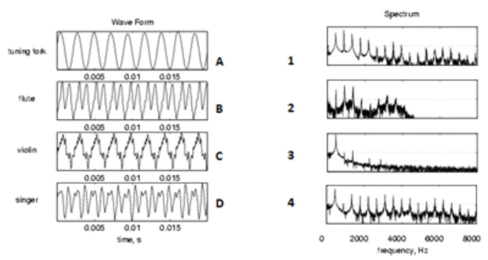
The color code shows the power in dB. The negative values are not to be confused with negative amplitudes. The topmost color (magenta) represents the highest amplitude of ground oscillation,

			whereas the bottom (cyan) represents the lowest amplitude.	
Use your imagination and make hypothesis – Choose potential solution	E, S	0.5 hrs	Using the knowledge you obtained on the use of the: waveform, the power spectrum and the spectrogram, brainstorm on how you could use these tools to answer our initial question: Why do different instruments, even ones belonging in the same family, sound differently? Work in groups and propose your methods of investigation.	.
CREATE (Investigate / Design) Plan the Investigation / Design the Prototype	M, S	0.5 hrs	In this investigation you will use the iMuSciCA drawing canvas in order to investigate the use of the waveform, the spectrogram and the power spectrum.  Picture 11 Using the drawing canvas, you can left click and drag your mouse to draw a shape. The vertical axis represents frequency and the horizontal axis represents time. By choosing the option: "Play" you can hear the sound of the shape you drew. The three windows on the left display the: waveform analyzer, the power spectrum and the spectrogram of the sound you produce.	
Carry out Investigation / Build the Prototype	M, S	1 hr	- Use the iMuSciCA drawing canvas and investigate the sound produced by the different color options using the information from your ear, the waveform, the power spectrum and the spectrogram. How would you do it? Would you draw any shape, or would you follow a specific procedure? Experiment and write down your observations. - Use the magenta color and draw two parallel horizontal lines: You just produced a beat! - Draw parallel lines in various distances and observe the output in the various tabs. Write down your observations. - Try to "draw" this simple melody and let it sound:	

			 Picture 12 - Repeat the procedure with the different color options and listen to the sounds produced. Fix the playback speed at the lowest value. Do the sounds sound differently or similarly? How do you perceive each sound? What is the frequency content of each sound? Can you answer why, even though you play the same notes, the music you produce with each color has different timbre? - Use the drawing canvas to write your own melody or a melody you like and let it sound.	

Title: Lesson Plan B2: Investigating the frequency content of a monochord's sound					
Description: In this lesson plan, students will analyze the sounds of everyday life as well as the sound of a virtual monochord and investigate its harmonic content. The lesson plan is addressed to upper high school students. The duration is 8 hours.					
E: Engineering/Technology, S: Science/Mathematics, M: Music					
Phase	**Field**	**Time**	**Description**	**Activity**	**Remarks**
CREATE **(Investigate / Design)** Plan the Investigation / Design	S,E, M	1 hr	In part 1 you will use the iMuSciCA audio canvas analyzer in order to listen to different external sounds and observe their harmonic content, using the knowledge you obtained on the previous lesson concerning the waveform, the power spectrum and the spectrogram.  Picture 1		

the Prototyp e			The iMuSciCA audio canvas analyzer imports the sound of your PC's microphone. The three windows on the right display the waveform, the power spectrum and the spectrogram of the sound. Part 2 In part 2 you will create a monochord playing note A and vary its parameters of interest as well as the way you interact with it in order to investigate which monochord attributes effect the timbre of the sound it produces. In order to create the monochord, follow the guidelines of scenario A, lesson plan A2: "Design a monochord playing note A". If you have already completed this lesson plan, open the saved instrument you have created and work with it.	
Carry out Investig ation / Build the Prototyp e	S, E, M	3 hrs	Part 1: - Plug a microphone in your PC. - Choose the microphone option of the analyzer. - Use different sound sources to produce sound. Listen to the sound and using the iMuSciCA analyzer observe its frequency content. You can use a whistle, clap your hands, have two people speak the same word, sing the same note in different octaves, trigger a tuning fork etc. -Open a word document in which you will write the name of the source you used and place below the screenshot of the waveform, the power spectrum and the spectrogram. - Click on this link: https://www.ee.columbia.edu/~dpwe/sounds/instruments/ and listen to the same note played by different instruments. For each instrument, note its name to your word document and take a screenshot of the waveform, the power spectrum and the spectrogram. - Now, play a song using two or more different musical instruments. If you don't have access to musical instruments, search youtube in order to find a song that you prefer and listen to it being played by different instruments. As before, write the title of the song, the instrument you used and sample some screenshots. Part2: - Using the monochord playing note A you created, let it sound. - Use the iMuSciCA analyzer to listen to the sound and observe the frequency contents of it. Take a screenshot of the power spectrum. What do you observe? Does the monochord play only note A (440Hz) or do we have overtones? - Keeping the tension of the string constant, vary the length starting from 0,5m until 2m in steps of 0,25m. For each step, calculate the fundamental frequency. Let it sound and take a screenshot of the various power spectra. What do you observe? - Now, use the leap motion tool in order to change the way you interact with the monochord using the available options. Keep the	

			fundamental tone constant at 440Hz. For different options, observe and take screenshots of the waveform and the power spectrum. - Alter the shape of the monochord keeping all other configurations constant and observe the power spectrum.	
Analyze Analyze Data from Investigations and Draw Conclusions/ Evaluate the Prototype.	S	1.5 hrs	Part 1 - Using the results you documented from Part 1, study the power spectra of the different sound sources you used. What are your observations concerning the frequency content of each sound? Write down your comments. - Using the results you documented on the same note being played by different instruments, note the differences between the different power spectra. Locate and estimate the frequencies occurring with highest intensity. Do different instruments have the same harmonic content? - Compare the power spectra you sampled from the same song with two different instruments. Note your observations. Part 2 - Observe the harmonic component of the sound produced by the monochord for each fundamental tone you have played. You will see that the overtones are different. - For each fundamental harmonic, find the frequencies which have the highest amplitude and divide them with the fundamental harmonic. Are the ratios constant? - Compare the waveforms and the power spectra of note A for different interaction configurations with the monochord. Does the harmonic content of the monochord's sound change with respect to the interaction method? With this comparison in mind, draw your conclusions. Why do different instruments of the same family sound differently?	
Explain by Relating to Background Knowledge/ Optimize the prototype	S,M	1 hr	- Match the following instrument waveforms with the correct power spectra  - Explain how you utilized the spectrogram, the power spectrum and the waveform in order to answer the question: "Why do different instruments sound differently". - Which instrument of the three has a more "clean" power spectrum: The violin, the cello or the guitar? - Is the sound produced by a tuning fork strictly monochromatic?	

			- When we use a monochord, what are the frequencies of the overtones we observe? Are they integer multiples of the fundamental frequency? - Make a short presentation with the instruments you employed and their power spectra.	
Describe and explain the results in the different STEAM-fields and the connections between them.	S, E , M	0.5 hrs	Discuss the design options of the monochord that contribute to the frequency content of the produced sound. Expand the discussion in other string instruments and discuss the design and the interaction parameters that may affect the sound output. You can use this link as reference: https://www.thoughtco.com/images-of-string-musical-instruments-4122917	
Communicate/Reflect Communicate Results and Conclusions / Communicate the Product, perform	M, S, E	1 hr	- Present your results in a powerpoint format and explain the reason why different musical instruments sound differently. - You can work in groups and make a live demonstration of the waveform, power spectrum and spectrogram tools employing different sounds, the same notes or sounds played with different musical instruments or a music performance of your own. - Make sure that you highlight the interconnections between the design of the instrument (engineering component), the sound timbre (music component) and the harmonics content of the sound (physics component).	
Reflect on Feedback and incorporate in further proce			- Discuss: What have you learned during this investigation. - Assume that you are an instrument maker. Would you take into account the harmonic content of your instrument while creating it? Would you listen to it and empirically try to Figure out the best design parameters, or would you employ scientific reasoning and tools in order to produce the optimal output? In this context, you could get in touch with instrument makers and interview them on the design considerations they have in order to produce high quality string instruments.	

ss			- Review the design of your monochord and evaluate which parameters were more important concerning the timbre of the instrument.	

Application in the National Curricula

The initial scenarios presented in section 5.5 can be applied in a variety of settings with minor adaptations as per the participant countries' national curricula.

Scenarios for junior high school

The scenarios 1: ***"Tone and noise"*** and 2: ***"Standing Waves and Resonant Frequencies"*** apply to junior high schoolers and can be implemented accordingly:

Greece:

- They can be implemented in the framework of the 3rd class of Junior high school (14-year-old students) during the lesson of Physics - chapters on oscillations and on waves/sound and could be combined with the "Creative activities" project hours. A connection with the Geometry section of 3rd grade mathematics could be attempted. Further connections with the subject of Music in the Music Schools could be investigated.

Belgium:

- They can be implemented in the framework of the STEM interdisciplinary subject for the 1st (12-14 year olds) and the 2nd (14-16 year olds) stage. A connection with the 1st stage music education in which students learn about the musical instruments could be attempted.

France:

- They can be implemented in the framework of technology education by means of connecting technology with maths and music in Cycle 4 of the junior high school curriculum. Connections with the music and maths education curricula could be investigated.

Scenarios for upper high school

The Scenarios A: " Investigating a monochord" and B: " Timbre and Power Spectra" apply to high schoolers and can be implemented accordingly:

Scenario A: "Investigating a monochord"

Greece:

- It can be implemented in project work for 15-17 year old students of the upper high school

- A light version of it can be implemented in the framework of the 3rd class of Junior high school (14 year old students) during the lesson of Physics - waves. This can be applied by omitting the fitting procedure during the analysis phase and replacing it with a more qualitative approach, showing that changes in tension and length have opposite effects in the frequency of the sound produced and also that the increase of frequency due to tension is slower than the steeper decrease of frequency.

- It can be implemented in the framework of algebra in the 1st class of upper high school, benefiting from the background knowledge of students in waves from the 3rd class of junior high school, throughout the chapters of functions and equations. It could be also implemented in the framework of algebra throughout the chapter of trigonometric functions in the second class of upper high school.

- It can be implemented in the third class of upper high school throughout the Physics chapter of waves, however, such an approach is not encouraged due to the students' preparation for the Greek National Exams.

- It can be implemented in Greek music schools in the framework of Music Technology in the 1st or 2nd class of upper high school.

Belgium:

- A light version might be implemented at the 2nd stage of upper high school (15-16 year old students) in the framework of a STEM interdisciplinary subject. Furthermore, the Music Education at the 2nd stage of upper high school could facilitate the implementation of this scenario.
- It can be implemented at the 3rd stage of upper high school (17-18 yer old students) in the framework of Physics Education, where the subject of waves is thoroughly analyzed. It can also be used in an interdisciplinary seminar in the 3rd stage.

France:

- It could be implemented at Grade 10 (15-16-year-old students) both within the framework of Music Education (Subject: "Voice and instruments") and in the framework of Physics (Subject: "Sound waves").
- It could be implemented at Grade 12 (17-18-year-old students majoring in Maths and Science), in the context of the subject of waves in Physics as well as in the Optional speciality: "Sound and music".

Scenario B: "Timbre and Power Spectra"

Greece:

- It can be implemented in project work for 15-17 year old students of the upper high school
- A light version of it can be implemented in the framework of the 3rd class of Junior high school (14-year-old students) during the lesson of Physics - waves and sound. This can be done by lightly discussing the power spectra and what they are, and by focusing on the more practical aspects of producing sounds and observing their output through the waveform. The functional form of waves should be also omitted and keep the discussion in a conceptual level.
- It can be implemented in the framework of algebra in the 1st class of upper high school, benefiting from the background knowledge of students in waves from the 3rd class of junior high school, throughout the chapters of functions and equations.
- It can be implemented in the framework of algebra throughout the chapter of trigonometric functions in the second class of upper high school.
- It can be implemented in the third class of upper high school throughout the Physics chapter of waves, however, such an approach is not encouraged due to the students' preparation for the Greek National Exams.
- It can be implemented in Greek music schools in the framework of Music Technology in the 1st or 2nd class of upper high school.

Belgium:

- It might be able to be implemented at the 2nd stage of upper high school (15-16 year old students) in the framework of the STEM interdisciplinary subject. Furthermore, the Music Education at the 2nd stage of upper high school could facilitate the implementation of this scenario.
- It might be implemented at the 3rd stage of upper high school (17-18 year old students) in the framework of Physics Education, where the subject of waves is thoroughly analyzed. It can be used in an interdisciplinary seminar too.

France:

- It could be implemented at Grade 10 (15-16 year old students) both within the framework of Music Education (Subject: "Voice and instruments") and in the framework of Physics (Subject: "Sound waves").

- It could be implemented at Grade 12 (17-18-year-old students majoring in Maths and Science), in the context of the subject of waves in Physics, Calculus in Maths, in the framework of Subject: "Trigonometric Functions" as well as in the Optional speciality: "Sound and music".

The long term project "Instruments of speech"

is based upon the curriculum for upper secondary in twenty teaching hours. It is designed to take place in a special 7-day summer-school in Greece related to Mathematics and it encourages the collaborative teaching between a music and a science teacher. It can be adopted as follows:

Greece:

- It can be done in the framework of a student project for the first grades of upper high school.

- It can be implemented in Greek music schools in the framework of Music Technology in the 1st or 2nd class of upper high school.

- For lower secondary during school hours the following adaptations can be made: 1) teacher can dramatically reduce the text lines and consequently the duration of the "Imagine" phase from four hours to one. 2) "Create" phase can be reduced from five to two 3) Likewise, Reflection phase can consist of one hour instead of four (FF analysis is kept).

Belgium:

- It might be able to be implemented at the 2nd and 3rd stage of upper high school (16-18 year old students) in the framework of a seminar or of STEM as an interdisciplinary subject. Furthermore, the Music Education at the 2nd stage of upper high school could facilitate the implementation of this scenario.

A restricted version of the project scenario can keep the following elements only: The voice analysis from the "Imagine" phase and a construction of one note from the "Create" phase.

France:

- It could be implemented at Grade 10 (15-16-year-old students) both within the framework of Music Education (Subject: "Voice and instruments"), in the framework of Physics (Subject: "Sound waves") and in the framework of Grade 12 for Maths education.

Scenario “Let’s hear Thales’s theorem”

Greece:

- A light version of it can be implemented in the framework of the 3rd class of Junior high school (14-year-old students) during the lesson of Physics - waves.

For lower secondary (3rd grade): If teacher allows the corresponding lesson from the book then the scenario can be fully implemented without uniform scaling (from the 1st “Create” phase) and by omitting 2nd time “Imagine” and “Create” phases (these phases deal with tension).

- The scenario can be implemented in the first grade of upper high school in the framework of Geometry during which the Theorem of Thales is taught.

- It can be implemented in Greek music schools in the framework of Music Technology in the 1st or 2nd class of upper high school.

Belgium:

- It might be able to be implemented at the 2nd stage of upper high school (15-16 year old students) in the framework of a STEM interdisciplinary subject. Furthermore, the Music Education at the 2nd stage of upper high school could facilitate the implementation of this scenario.

France :

In France Thales’ theorem is part of the curriculum at an earlier grade. Teacher is needed to recall the corresponding lesson for the students. For earlier grades, the scenario can be adapted the same way as described for Greece.

6. Towards a strategy for implementation of pedagogical innovation in the educational scenarios

iMuSciCA proposes an innovative pedagogical design which utilizes cutting edge technological solutions in order to foster students' Deeper Learning in STEM subjects through the design and performance of digital musical instruments. An interdisciplinary, inquiry based pedagogy across STEAM fields has been developed and is implemented through the iMuSciCA educational Scenarios. For further information, the reader is encouraged to consult Deliverables D2.1 "*Initial Pedagogical Framework and use cases by teachers and learners*" and D2.4: *"Intermediate Pedagogical Framework and use cases by teachers and learners".*

In the present deliverable, the educational scenario architecture was presented; the relevant STEAM subject content to be addressed as well as the connections to the Belgian, French and Greek national curricula have been established:

- A flexible modular structure for the design of iMuSciCA educational scenarios has been developed: the variations between the participating countries' National Curricula, the structural differences between the public schools, music schools and private schools as well as the everyday classroom reality, provide a landscape which requires flexibility and adaptability in the architecture of iMuSciCA educational modules. The design of the educational modules takes into account these factors. The structure of the educational scenarios can adapt in long term project based work that can be carried out in school clubs, as well as in medium term regular classroom interventions dedicated to iMuSciCA or in short termed classroom interventions which go on par with the school curriculum. The last two cases depend on the school's flexibility and availability.
- A thorough investigation on the STEM related difficulties and misconceptions of students relevant to the scope of iMuSciCA has been made, justified by the fact that deep content knowledge is considered one of the pillars of deeper learning. Based on this, a first outline of the subject content thematology that the iMuSciCA educational scenarios need to address has been proposed. In the following versions of this deliverable, this thematology will be reconsidered, reformulated and finalized in cooperation with teachers and students and will be realized in the form of the final educational scenarios and projects.
- A detailed investigation of the connections of iMuSciCA and its STEAM content to the national curricula of the countries that participate in the iMuSciCA implementation activities has been conducted. According to the findings of this research, the potential for short term or long term in-classroom interventions as well as project based activities has been mapped per participant country.

The initial educational scenarios presented in this document have been designed by the iMuSciCA consortium taking into account the aforementioned points and have been successfully tested with teachers during Phase A implementation activities (for further information, the reader is referred to D6.2 - *Interim report on teacher's feedback and pilot testing in schools (A-Cycle)*).

The path towards the intermediate and final pedagogical scenarios: a proposed strategy iMuSciCA wants to achieve the highest possible impact in attracting students' interest in STEM through the iMuSciCA approach, in reaching out to interested students and teachers both within and beyond the countries involved in the project's implementation and in achieving an increase in students' deeper learning in STEM. The challenges that the iMuSciCA pedagogical design faces can be summarized in the following points:

- Harnessing the full potential of the state-of-the-art tools integrated in the iMuSciCA workbench as well as the flexibility for utilization of more than one tools of those offered by the workbench when designing the pedagogical scenarios.
- The full exploitation of the iMuSciCA inquiry based interdisciplinary pedagogy across the STEAM fields, using a scheme which includes both guided and open inquiry practices.
- The design of iMuSciCA scenarios which will be smoothly integrated in the school practice of Belgium, France and Greece taking into account the individual characteristics of each country's educational landscape.
- The design of pedagogical scenarios and projects which could be offered to be used in both formal and informal environments beyond the countries, and thus the educational systems, involved in the project's implementation.
- The evaluation and development of students' 21st century skills associated with Deeper Learning: deep content knowledge, collaboration, communication, learning how to learn, individual and collaborative problem solving.

In order to address these challenges, the iMuSciCA consortium will build on the results achieved and documented in this deliverable and will:

- Maximize the pedagogical use out of each tool in each scenario. The tools utilized will be documented in each scenario metadata.
- Formulate the scenarios in a fashion appealing and motivating, both in terms of presentation and in terms of approach from different STEAM fields.

The scenarios will support a transition from guided inquiry across STEAM fields, to open inquiry via the use of dedicated logbooks and free inquiry in the framework of which students will be able to perform activities of their own inspiration and design, navigating freely through the iMuSciCA workbench.

Following the above considerations, the iMuSciCA pedagogical team will collaborate with both STEM and Music teachers in order to:

- Finalize the roadmap of subjects' content thematology (the "*iMuSciCA curriculum*") which will be addressed by the iMuSciCA educational scenarios.
- Co-Create innovative inquiry based educational scenarios which will be able to be applied both in and out of school in formal and informal learning environments. The final version of these scenarios will be publicly accessible.
- Encourage the collaborating teachers to utilize the already existent lesson plans and scenarios in order to form their own iMuSciCA scenarios and projects which will be implemented in real settings.
- Encourage students involved in iMuSciCA implementations to perform their own inquiries using the iMuSciCA workbench and document their results.
- Co-Create and design iMuSciCA projects which can be implemented both in formal and informal settings, both in and beyond the educational systems of the three implementation countries of the project.

These developments will be documented in the following versions of this deliverable.

7. Future outlook

In this deliverable, the initial iMuSciCA educational scenarios have been presented. The pedagogical framework structure and the pedagogical value of the iMuSciCA workbench have been outlined. The authors have investigated the National Curricula of the three piloting countries (France, Belgium and Greece) and have identified the potential landscape for iMuSciCA interventions both in terms of project based work and in terms of short termed consequent interventions in the school curriculum. Furthermore, a thorough investigation has been made on the misconceptions and difficulties that the students face in the Physics of Waves and Sound, Mathematics and Engineering. This investigation determined the pedagogical goals of the iMuSciCA educational scenarios as it is very important for students to master core academic content in order to achieve deeper learning in STEM through music in terms of creating virtual musical instruments.

Following the findings discussed in this document, the educational scenario structure has been defined and a proposed iMuSciCA curriculum has been outlined, aiming to be flexible for implementation in different educational settings and systems, to provide the pathway with which students will be able to achieve Deeper Learning in STEM through the creation of virtual musical instrument and be engaging and user friendly in order to facilitate the increase of students' interest in Scientific Careers.

The initial scenarios of iMuSciCA which will be implemented during Pilot Testing Phase A have been presented and followed by a proposed strategy for implementation of pedagogical innovation in the educational scenarios. This strategy will be implemented in the two coming versions of this Deliverable, namely: Deliverable 2.6 "*Intermediate Educational Scenarios and Lesson Plans*" (M15) in which the final iMuSciCA curriculum will be presented and will be accompanied by the intermediate educational scenarios, which will be co-created by the iMuSciCA pedagogical team and by teachers and students; Deliverable 2.8 "*Final Educational scenarios and lesson plans*" (M18) in which the final educational scenarios as well as the broader iMuSciCA projects will be documented.

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Appendix

iMuSciCA Templates

Synopsis

<table>
<tr><td colspan="6">Title:</td></tr>
<tr><td colspan="6">Description:</td></tr>
<tr><td colspan="6">E: Engineering/Technology, S: Science/Mathematics, M: Music</td></tr>
<tr><td>Phases</td><td>Field</td><td>Time</td><td>Description</td><td>Activity</td><td>Remarks</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

SCENARIO METADATA

An Educational Scenario consists of one or more Lesson Plans, with the following restrictions:
An educational Scenario must go through all the inquiry phases and all the STEAM fields. Following these considerations, the Scenario Metadata consist of the following 2 elements:

Table 1: General Metadata

General Metadata

Title:			
Keywords:			
Short Description:			
Lesson Plans included:	Lesson Plan 1: Title Lesson Plan 2: Title ….	Date:	
Educational Objectives:		Estimated Duration:	
Author(s):		Age Group:	10-12/12-14/14-16/16-18
Contributor(s):		Language:	
Status:	Draft / Final	Difficulty Level:	High/Medium/Low
Dissemination level:	Public/Custom	Special Needs Addressed:	Yes/No

Table 2: Inquiry Phase and STEAM Field

STEAM field

Inquiry Phase

	Music	Science – Math	Technology
ENGAGE	E.G Lessson Plan 1		
IMAGINE		E.g Lesson Plan 2	
CREATE		E.G Lesson Plan 3	
REFLECT		E.G Lesson Plan 4	
COMMUNICATE	E.G lessonplan 5		

* All inquiry phases and STEAM fields need to be addressed or the scenario will not be able to be saved

<u>Comments</u>

1. In order to be able to save the Scenario, all inquiry phases and STEAM fields need to be addressed.
2. Both tables are to be filled by the author.
3. The lesson plans could be viewed individually or in common.

SCENARIO STRUCTURE

Since a scenario consists of multiple lesson plans, there are two potential options:

1. To have a common table where all lesson plans are presented per inquiry phase (Like Table 2). The numbers (Lesson plan 1, Lesson plan 2..) indicate the order by which lesson plans should be studied.
By clicking on each lesson plan, the user will be able to see the respective lesson plan individually (see the Demo Lesson Plan.doc)

2. Once the user chooses to "Start the Scenario" and presses the respective option, then all the Lesson Plans are appended to each other and present a full scenario.
Lesson Plan 1 goes first, Lesson plan 2 goes second etc.

Potentially, the first thing that the end user sees when he/she uses the scenario is the following table:

STEAM field

Inquiry Phase

	Music	Science – Math	Technology
ENGAGE	E.G Lessson Plan 1		
IMAGINE		E.g Lesson Plan 2	
CREATE		E.G Lesson Plan 3	
REFLECT		E.G Lesson Plan 4	
COMMUNICATE	E.G lessonplan 5		

Start iMuSciCA Scenario

If they Click on each individual Lesson Plan (Color), they are redirected to the lesson plan itself. If they click on "Start iMuSciCA Scenario", the lesson plans are appended and produce a common document with all inquiry phases incorporated.

ENGAGE

Wonder, Ask Questions, Explore, Observe– Identify Problems, questions and chances

Relate to Background Knowledge

IMAGINE

Identify relevant variables to investigate – Identify Relevant Solutions to use

Use your imagination and make hypothesis – Choose potential solution

CREATE
(Investigate / Design)

Plan the Investigation / Design the Prototype

Carry out Investigation / Build the Prototype

ANALYZE

Analyze Data from Investigations and Draw Conclusions/ Evaluate the Prototype

Explain by Relating to Background Knowledge/ Optimize the prototype

Describe and explain the results in the different STEAM-fields and the connections between them.

COMMUNICATE/REFLECT

Communicate Results and Conclusions/ Communicate the Product, perform

Reflect on Feedback and incorporate in further process