Interactive Music Science Collaborative Activities
Team Teaching for STEAM Education

Deliverable 2.8
Final Educational Scenarios & Lesson Plans for iMuSciCA

Date:	24/07/2018
Author(s):	Emmanuel Chaniotakis (EA), Petros Stergiopoulos (EA), Thomas Fischer (EA)
Contributor(s):	Renaat Frans (UCLL), Erica Andreotti (UCLL), Colette Laborde (CABRI), Vassilis Katsouros (ATHENA)
Quality Assuror(s):	Daniel Martín-Albo (WIRIS), Colette Laborde (CABRI), Pierre Laborde (CABRI)
Dissemination level:	PU
Work package	WP2 – Pedagogical framework and pedagogical engineering for teaching STEM with Music
Version:	1.0
Keywords:	STEAM, pedagogy, learning, workbench, interdisciplinary, teachers, students, scenario, project, lesson plan, activity, curriculum
Description:	Report on the final educational scenarios and lesson plans for iMuSciCA.

Horizon 2020
European Union Funding for Research & Innovation

H2020-ICT-22-2016 Technologies for Learning and Skills
iMuSciCA (Interactive Music Science Collaborative Activities)
Project No. 731861
Project Runtime: January 2017 – June 2019

Executive Summary

This document presents the final version of the iMuSciCA educational scenarios, building upon the deliverables D2.6-Intermediate Educational scenarios and lesson plans for iMuSciCA and D2.7-Final Pedagogical Framework and Use Cases by learners and teachers.
The iMuSciCA lesson plans, created and described in D2.3-Initial Educational scenarios and lesson plans for iMuSciCA and D2.6-Intermediate Educational scenarios and lesson plans for iMuSciCA are integrated in iMuSciCA educational scenarios and have been implemented in phase B1 piloting (April-July 2018) in Belgium, France and Greece. These implementations have been conducted in three levels: (i) long term implementations (Student clubs, long term in-classroom interventions), (ii) mid-term implementations (for example the iMuSciCA summer Camp in Greece) and (iii) short term implementations (a few hours in-classroom implementations, where individual lesson plans were tested). The implementation in these settings created the conditions of providing feedback to the iMuSciCA pedagogical partners regarding the educational scenarios and is presented in section 1 of this document. The student and teacher feedback will be presented in detail in D6.3-Final Report on Teacher Feedback and piloting in schools.
The final version of educational scenarios successfully incorporates the acquired feedback of teachers and students and is presented in section 3.2 of this document. The iMuSciCA consortium has organized extensive teacher training, which took place during the iMuSciCA Summer School 2018. The participant teachers received extensive training in the iMuSciCA pedagogy, technology and educational scenarios and collaborated among themselves and with the iMuSciCA experts to produce new teacher-oriented educational scenarios. These scenarios are presented in section 3.3 of this document. To demonstrate a successful use case scenario, in Appendix 2 we present the scenario of the iMuSciCA summer camp.
The latest version of iMuSciCA educational scenarios also benefits from the developments of the iMuSciCA core enabling technologies incorporated in the iMuSciCA workbench and the new features of the tools, highlighting the broad and in depth use of all the workbench learning environments. The current status of the workbench is presented in Appendix 1 of this document.

Version Log			
Date	**Version No.**	**Author**	**Change**
17-07-2018	0.1	Petros Stergiopoulos (EA), Emmanuel Chaniotakis (EA), Thomas Fischer (EA), Vassilis. Katsouros (ATHENA), Renaat Frans (UCLL)	Initial Structure & Content
19-07-2018	0.2	Renaat Frans (UCLL)	First Internal Review & Adaptations
23-07-2018	0.3	Emmanuel Chaniotakis (EA), Daniel Martin Albo (WIRIS), Colette Laborde (CABRI)	Second Internal Review & Adaptations
24-07-2018	1.0	Vassilis Katsouros (ATHENA)	Submission to the EU

Disclaimer

iMuSciCA is an H2020 project funded by the European Union.

TABLE OF CONTENTS

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
LMS	LEARNING MANAGEMENT SYSTEM
TT	Teacher Training
LCAT	Learning Content Authoring Tool

1. Overview of the Implementation and Piloting of iMuSciCA

This section describes the conditions which allowed the iMuSciCA consortium to acquire feedback from teachers and learners regarding the iMuSciCA educational scenarios.

During the Piloting Phase B of iMuSciCA, which took place from April to July 2018, the following main sources of information and feedback have been utilised in order to refine and improve the existing Educational Scenarios and Lesson Plans as well as provide feedback regarding the iMuSciCA digital environments as collated on the iMuSciCA workbench: (i) feedback from educators participating in teacher trainings or in the iMuSciCA Summer School, which took place from 01 to 06 July 2018 in Marathon in Greece; (ii) feedback was obtained from the in-service teachers involved in the piloting in schools in Belgium, France and Greece. Equally important have been (iii) the reactions of the students, who have been learning with the iMuSciCA workbench and related Scenarios e.g. again during the piloting in three European countries as well as iv) through the Student's Club and a one week long Summer Camp organised by Ellinogermaniki Agogi in Greece.

As a result of all this feedback, which will be consistently presented in D6.3 Final Report on Teachers Feedback and Piloting in Schools, the Workbench and the Educational Scenarios were improved constantly. For instance the inquiry questions were optimised throughout most of the Educational Scenarios; certain formulations, tables and graphs were simplified, based on the experiences obtained by the in-classroom applications. Clearer examples were added and sometimes even also activities, tasks and exercises. Due to asked new functionalities of the Tools sometimes entire Educational Scenarios or parts of them were rewritten.

Some Educational Scenarios were more elaborated towards a more attractive pedagogy like ‘Make your own String Instrument’ or ‘Create your own Piece of Music with Mathematical Symmetries’. Musical expressions were added many times thanks to the new possibilities of the Activity Environments like for instance the 3D Instrument Interaction environment that give students the possibility to play virtual instruments even those they have created themselves.

It should be finally noted that improvement of the existing Educational Scenarios goes on par with the technical development of the iMuSciCA Workbench and its Activity Environments and Tools. Table 1.1 summarises the number of teachers and students, who participated in the Piloting Phase B1 of iMuSciCA.

Table 1.1.: Participants in the Piloting Phase B1 of iMuSciCA

	Piloting Phase B1 (April – July 2018)			
	Teachers		Students	
	M	F	M	F
Greece	11	12	59	64
France	1	3	8	13
Belgium	13	14	141	137
TOTAL	25	29	208	214
TOTAL	54		422	

The results of the multi-dimensional and -methodological evaluation of the service portfolio of iMuSciCA by educators and students from three European countries will be reported in detail in D6.3. Final Report on Teacher's Feedback and Pilot Testing in Schools (B-Cycle) as well as in D6.4 Quantitative and Qualitative Results of Learners - Aspects of Deeper Learning.

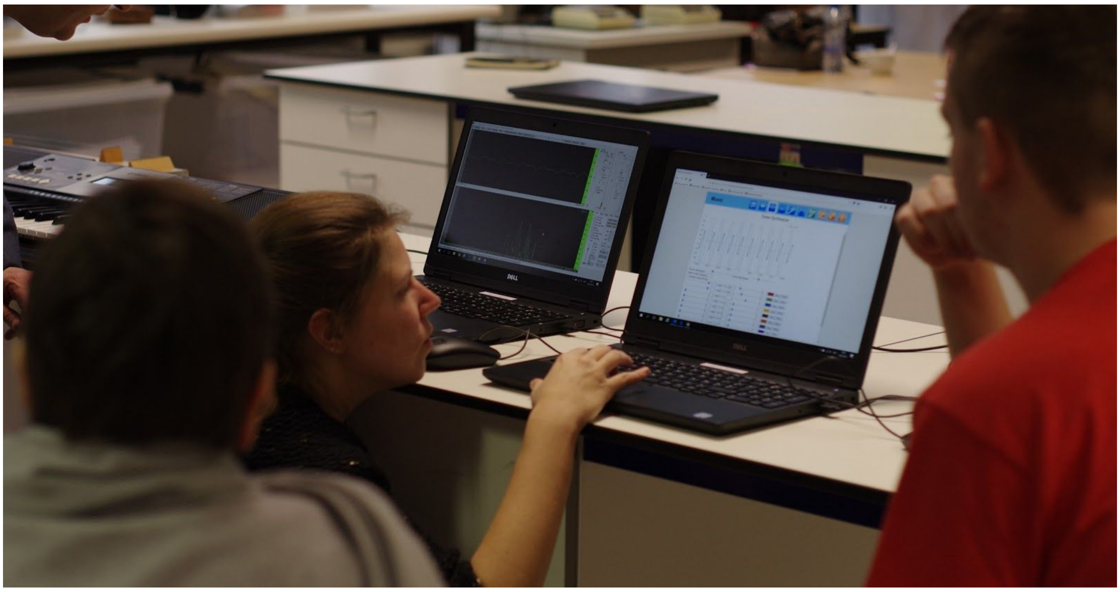

Figure 1.1.: Teachers playing with the iMuSciCA Activity Environments during a Teacher Training (TT) Event

Figure 1.2: Moments from the iMuSciCA student summer camp taking place in Ellinogermaniki Agogi, Greece: Students learned about the Physics and Music behind musical instruments, they created their own instruments, 3D printed them, produced a musical synthesis and performed with them.

2. The iMuSciCA Educational Scenarios

2.1. Introduction

The Educational Scenarios of iMuSciCA are based on the developed Pedagogical Framework combining the Inquiry Based Science Education (IBSE) model with the integration of three fields of STEAM: Science-Mathematics, Engineering and Music. Following these developments, with alongside the continuous technical development of the iMuSciCA Workbench (incl. Activity Environments and Tools), the pedagogical team has refined the existing initial Educational Scenarios and co-created with teachers new Educational Scenarios. By these means an 'iMuSciCA Curriculum' is articulated, which is defined as a full sequence of Educational Scenarios. These scenarios will be applicable to all national curricula either directly implemented in classroom settings during science lessons or in the framework of Project Based Learning activities e.g. in the afternoon or even extra-curricular.

Table 2.1.1: Summary table of the iMuSciCA educational scenarios, their status and their changes with respect to previous versions

Scenario Title	Status	Changes in the scenario
1. Sound and tone	**Final**	This scenario was piloted in December 2017. After the structure, questions, formulations were improved. It was again piloted in April, May 2018 thereafter still some improvements were made. In the meantime many tools were updated too. For instance the possibility to record a sound and measure it thereafter. To measure a sound on external mic source and to measure internal instruments like the virtual ones of the 3D environment (monochord). This resulted in some updates in the scenario as well.
2. Standing Waves & Natural Frequencies	**Final**	This scenario was piloted in March 2018. Based on that experience some concepts and formulation seemed too difficult for the age group aimed at. This resulted in providing more background and more careful and more gradual use of new concepts. There were some difficulties reported to the developers on the gauging of the frequency measurements. In many cases a systematic deviation of ca. 8-10% was measured by iMuSciCA's spectrum analyser in comparison to the real value. Numerous measurements were made both by teachers, the pedagogical team and the developers in order to solve the problem. Other wishes from the teachers were given to the developers among them: - add names to the axes (frequency, time); - a save option or something that makes it possible to visualize a previous measurement;

		- a finer scale and a possibility to click on spectrum peaks in order to read more exactly the measured value; - an accumulation option in order to measure spectrum of weak signals.
3. Synthesize the Timbre of your preferred Instrument	**Final**	This scenario was improved as result of teachers input during a teacher training held in UCLL in February (and again in May 2018). To make it more pedagogically attractive for students, the scenario was rewritten around a clearer main task: make the timbre of your favorite instrument. This resulted in extensive make over of questions, tasks and formulations. There was also intensive feedback given to the developers of the tone synthesizer: a larger frequency range was requested and some bugs were reported and solved. The improved scenario was then piloted in the schools in April and May 2018. After that still some minor flaws were corrected.
4. Create a Piece of Music using Geometric Symmetries	**Final**	This scenario was tested in February with teachers, then it was re-written: a shorter and pedagogical more attractive version was made to let students more directly draw their own tune based on drawing patterns that contain mathematical symmetries. This new version was then tested again in schools in June 2018 and teachers feedback was asked during the teacher training in May 2018. During this training teachers helped finishing the final version. On the suggestion of teachers inquiry questions were added or improved throughout the scenario, in the graphs quantity labels of time and frequency were added, help lines were added that will help students to draw the right height of the tone. In the geometrical drawings a reference line was added and new clearer examples were added. More exercises making use of iMuSciCA's DrAwMe tool were added. The scenarios ends now more clearly when every student shows his or hers tunes, the result of using geometrical symmetries.
5. Make your own String Instrument	**Final**	This scenario was developed more towards a clear attractive goal: make your own virtual string instrument. It was co-created during the teacher trainings of February and May 2018 and then piloted in school in June 2018. During this cycle of optimisation a lot of feedback was given to the developers of the 3D virtual instrument design as well as to the developers of the sound engine. It had to do with a slow performance and low quality of the sound. It made practice

		in class difficult if not impossible. Happily, performance was improved in a new stable and lighter version of the workbench.
6. Let's hear Thales' Theorem	**Final**	Same as D2.6
7. Investigating the Monochord	**Final**	Updated with new workbench links. Second lesson plan title has been altered from "Design a Monochord Playing Note A" to "Design your monochord". Finding the optimal arrangement of variables in order to produce Note A for the monochord has been added as extra exercise. New images have been added which enhance students' understanding of concepts such as the harmonics of a string. New activities have been introduced in order to tackle the students' difficulty in correlating linear and volume density of an object.
8. Instruments of Speech (Vol. 1)	**Final**	Same as D2.6
9. Instruments of Speech (Vol. 2)	**Final**	Updated with new workbench links. Utilizes the new use of the microphone and the option to use Leap Motion in the Tone Synthesizer tool.
10. The House of Chords	**Final**	Same as D2.6
11. Listen to your Math	**Final**	Updated with the new workbench links. Utilizes the new copy and paste functions of the workbench.
12. Let's play Sectio Canonis (Vol .1)	**Final**	Same as D2.6
13. Let's play Sectio Canonis (Vol. 2)	**Final**	New educational scenario
14. Timbre and Power Spectra	**Final**	Updated with the new workbench links and the option to use Leap Motion in the Tone Synthesizer tool
15. Defining the Octave	**Final**	New educational scenario

16. iMuSciCA Summer Camp 2018	**Final**	New educational scenario
17. Understanding Science through Music	**Final**	New educational scenario created by teacher during the iMuSciCA summer school 2018
18. Sound, tone & silence	**Final**	New educational scenario created by teacher during the iMuSciCA summer school 2018
19. The Chladni Patterns	**Final**	New educational scenario created by teacher during the iMuSciCA summer school 2018
20. The human ear	**Final**	New educational scenario created by teacher during the iMuSciCA summer school 2018
21. Draw the music you hear	**Draft**	New educational scenario under development created by teacher during the iMuSciCA summer school 2018
22. Learning about Algorithms	**Draft**	New educational scenario under development created by teacher during the iMuSciCA summer school 2018
23. Listening to the Harmony of Chemical Elements	**Draft**	New educational scenario developed and being currently translated by teacher during the iMuSciCA summer school 2018
24. Pentatonic	**Draft**	New educational scenario under development created by teacher during the iMuSciCA summer school 2018
25. Research of the human voices	**Draft**	New educational scenario under development created by teacher during the iMuSciCA summer school 2018
26. Make your own personalized ringtone	**Draft**	New educational scenario under development created by teacher during the iMuSciCA summer school 2018

2.2. iMuSciCA Educational Scenarios Piloted in European Schools

In the following the iMuSciCA Educational Scenarios (and Lesson Plans) are presented, which have been developed by the pedagogical partners of the iMuSciCA consortium and were consequently piloted in schools. Upon feedback of these teachers and as a result of careful classroom observations, these scenarios were updated several times and on consecutive basis. Moreover based on this piloting detailed feedback was given to the developers of the different tools on the basis of which all of the activity environments and tools were updated. These updated tools formed then the occasion again to improve the scenarios. This feedback loop worked many times and numerous documents were made and distance meetings were organised to streamline this information flow between teachers, pedagogical team and developers. This makes the Educational Scenarios of iMuSciCA unique in their kind.

Figure 2.2.1.: iMuSciCA Educational Scenarios & Workbench during Piloting Phase B1

The resulting scenarios were acting as demonstrators as well: activities during Teacher Trainings (TT) that were organised by UCLL and EA. The scenarios were also input and inspiration material for iMuSciCA Educational Scenarios that were developed by the teachers in the Summer School. The teacher trainings and the summer school functioned again as a feedback loop to the pedagogical team and the developers.

The philosophy and structure of the Educational Scenarios have been reported before in deliverables D2.6-Intermediate Educational scenarios and lesson plans for iMuSciCA and D2.7-Final Pedagogical Framework and Use Cases by learners and teachers you will find a functional pedagogical guide for teachers.

Table 2.2.1 gives an overview of the different Educational Scenarios, a short description of each, the age group they are meant for, the Activity Environments and Tools that are used and links to the detailed description. The Educational Scenarios contain a large number of background information, which allows teachers to use them in real classroom settings.

Table 2.2.1.: Short Description of Educational Scenarios Piloted in Schools & Relation to the Workbench

Title	Age group	Description	Workbench tools utilized
Sound and tone	Lower Secondary School	The students investigate the vibrations as sources of sound. By means of the iMuSciCA visualisation tools they measure sounds and recognise that some are periodic, and others aren't. They learn to connect this insight with what they can hear: some sounds have more tone, some others less or no tone at all. This scenario introduces the notion of frequency, period, the unit Hertz and includes the	Visualisations DrAwME Metronome Performance Sampler Geometry &

		calculation of frequencies and periods. It consists out of two lesson plans: 1.1 Sources of Sound and Music 1.2 What is Tone?	Algebra
Standing Waves & Natural Frequencies	Lower Secondary School	The students investigate the natural sequence of tones that do occur on string instruments and aerophones. With the iMuSciCA analyser tools on the workbench they measure the frequencies and discover their mathematical relation. Moreover, they try to understand how a specific sequence of tones can occur on an instrument where you don't change anything. This scenario consists of three lesson plans: 2.1: The Sequence of Natural Tones 2.2: Natural Tones & Standing Waves 2.3 How do Standing Waves occur?	Visualisations DrAwME
Synthesize the Timbre of your preferred Instrument	Lower Secondary School	The scenario 'Synthesize the Timbre of your preferred Instrument' is built around the workbench tool 'Tones Synthesizer'. In this scenario the student has the task to recreate the timbre of his or her favourite instrument.	Tone Synthesizer Visualisations Music Tools
Create a Piece of Music using Geometric Symmetries	Lower Secondary School	The scenario 'Create a Piece of Music using Geometric Symmetries' let students make their own tune. Moreover they discover that a musical motive contains patterns, that you can reuse your idea by transforming it, by drawing it, by making combinations of music and geometry! It uses various iMuSciCA tools on the workbench like the Performance Sampler, DrAwME' and Geometry & Algebra. This scenario consists out of following lessons: 4.1: Discovering symmetry in music and mathematics 4.2: Transformations in music and mathematics 4.3: Combinations of transformations in music and mathematics	Performance Sampler Geometry & Algebra DrAwME

Make your own String Instrument	Lower Secondary School	The Scenario 'Make your own String Instrument' is built around the iMuSciCA workbench tool '3D Musical Instrument Design'. The aim of this scenario is that the students create their own virtual string instrument like a violin, a (bass) guitar or a cello. At the end they can play with their virtual instrument using the iMuSciCA's 3D interaction tool.	3D Virtual Instrument Design Visualisations 3D Instrument Interaction
Let's hear Thales' Theorem	Upper Secondary School	Within the Scenario 'Let's hear Thales' Theorem' students use the tools of 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 listening to its different corresponding lengths (or areas). They select a number of string-lengths (or surfaces) to form their own 'scale' in a polychord (e.g. bichord, trichord, tetrachord etc) or in more than one in case of membranophones. With the help of their music teacher, they use this scale to compose motifs (i.e. 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.	DrAwME Geometry & Algebra 3D Virtual Instrument Design Sound Recorder Performance Sampler 3D Instrument Interaction
Investigating the Monochord	Upper Secondary School	This seven-hour-long Educational Scenario introduces students to the science behind the sound produced by the simplest stringed instrument, the monochord. 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, such as the string tension, radius and length. To do that, they will produce a virtual monochord using '3D Design Environment' in the iMuSiCA Workbench and will experiment in a hands and minds on fashion with the relevant parameters and investigate the aforementioned dependencies using	3D Virtual Instrument Design Visualisations Tuner 3D Instrument Interaction

		simulated data produced by the performance of the virtual instrument.	
Instruments of Speech (Vol. 1)	Upper Secondary School	This meta-scenario is an early investigation for utilising all possible existing digital tools of the iMuSciCA Workbench in the form of a unified 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 scenario the monochords interpret a series of variations around a melodic sequence.	3D Virtual Instrument Design Visualisations (2D Analyser) 3D Instrument Interaction Tone Synthesizer DrAwME
Instruments of Speech (Vol. 2)	Upper Secondary School	In the refined second version of the Educational Scenario 'Instruments of speech' students identify and analyze the harmonic content of their voices and subsequently create virtual musical instruments aiming to produce sound with similar power spectrum to that of their voice. Throughout the course of this educational scenario, students are taught about musical notes and scales, about the design of virtual monochords and the crucial parameters affecting their performance, about wave interference and the creation of beats and about the power spectrum and its use to identify the harmonic content of a sound. The scenario lasts 20 school hours.	3D Virtual Instrument Design Visualisations (2D Analyser) Tuner 3D Instrument Interaction Tone Synthesizer DrAwME
The House of Chords	Upper Secondary School	In the Educational Scenario entitled 'The house of chords' students will understand how the idea of chords is being produced and how the combination of chords leads to harmonic sequences. They investigate given consonances and dissonances of different tones according to ear and data analysis. Students experiment with the compilation of two, gradually three, tones produced in the tone synthesizer and analyze their observations using their ear in combination with the measurements taken from the workbench analyzing toolkit. With the help of their Music teacher, they draw a score of	3D Virtual Instrument Design Geometry & Algebra Tone Synthesizer 3D Instrument Interaction Snail

		consonances or dissonances as a result of building chord sequences and finally they record it using the virtual instruments produced to play it.	
Listen to your Math	Upper Secondary School	The Educational Scenario 'Listen to your math' introduces students to the techniques of sonification. Combining the teaching of mathematical functions with music, students utilize the sonification tool of the iMuSciCA workbench to sonify different mathematical functions relevant to their curriculum and create a soundscape.	DrAwME Sonification Geometry & Algebra Sound Recorder Math Editor
Let's play Sectio Canonis (Vol .1)	Upper Secondary School	Within the Educational Scenario 'Let's play Sectio Canonis' students take the division of the string using the intercept theorem as described in the 'Let's Hear Thales' theorem' and start investigating synergies of consonances and dissonances derived by the similar triangles produced in each section. Students experiment with their own similar triangles by composing sequences of tones derived from their sides and eventually by constructing the virtual instruments to play them.	3D Virtual Instrument Design Geometry & Algebra Tone Synthesizer 3D Instrument Interaction
Let's play Sectio Canonis (Vol. 2)	Upper Secondary School	In the second version of 'Let's play Sectio Canonis' students develop a segment division in 2, 3, 4, 5, and 6 equal parts. They investigate the properties of each part along with the triangles produced. They continue measuring further divisions and they write down their conclusions. At the end, students explore the hypotenuses of the triangles and their properties forming a minor chord.	3D Virtual Instrument Design Geometry & Algebra Tone Synthesizer 3D Instrument Interaction Snail
Timbre and Power Spectra	Upper Secondary School	The Educational Scenario 'Timbre and Power Spectra' lasts 12 teaching hours in total and addresses students of Upper Secondary Education and beyond, aiming to introduce them to the physics of wave interference and the investigation of the	Tone Synthesizer. DrAwME

		harmonic content of sound. Students will experiment with different virtual musical instruments and investigate why different instruments sound differently. They will analyse different sounds and comprehend the connection of the timbre of a musical instrument with the harmonic content of the produced sound. In order to achieve that, students get acquainted with the powerful analysis tools of the power spectrum and the spectrogram.	3D Virtual Instrument Design 3D Instrument Interaction Visualisations
Defining the Octave	Upper Secondary School	This scenario is focused on presenting the differences between the tempered and the diatonic scale. Students observe the differences between the two notes of an octave interval namely C'' on 261 Hz and C'''. They produce a progression of the 13 consecutive terms of the geometrical progression in between the doubled frequency. They finally observe the differences between tempered and diatonic scale in ratios 1/1, 8/9, 4/5, 3/4, 2/3, 3/5, 8/15, 1/2.	Sonification Visualisations Tone Synthesizer
iMuSciCA Summer Camp 2018	Upper Secondary School	Summer Camp Scenario was designed to be implemented during the iMuSciCA Summer Camp that took place in Ellinogermaniki Agogi. The scenario is addressed to students in a transdisciplinary class including participants with different background from both Sciences and Music. During the scenario students are introduced to a variety of topics covering both the disciplines of acoustics and music. Students are introduced in the theory of frequency and timbre through the measurement of real instruments and come to conclusions about music consonances and vibrating lengths. Musical concepts of consonance such as the“elements of musical praxis” are combined with their conclusions on Mersenne's law in order to produce a unique music-event coming out from both virtual, 3D- printed and real instruments. Students experiment with 3D- printed tube-instruments and calibrate their performance after defining	3D Virtual Instrument Design Geometry & Algebra Tone Synthesizer 3D Instrument Interaction DrAwME Math Editor

		their lengths according to a musical piece generated on the spot. The scenario finishes with a small live performance of the piece coordinated by the teacher.	

The lower secondary school educational scenarios and upper secondary scenarios follow a similar structure and display pedagogical coherence.

For lower secondary school, in the center we find two 'basic' scenarios which contain basic concepts of music, physics and mathematics, e.g. what are the sources of sound and tone, what is a tone, what are natural tones, etc. These two scenarios are built in a quite guided way. The can be a good starting point for those, mostly young students in need for some guiding. Direct links to the appropriate tools on the iMuSciCA workbench are included. This guided form is very useful as a start in classes of the 7th and 8th grades (12-14 years old), but it can be implemented even in the 9th grade (15 years old pupils) as experienced during the iMuSciCA piloting phases. Although guidance is given, groups of students can work independently by following an inquiry path. It is important that students at this level learn to perform some inquiries themselves, formulate their own conclusion. The 'Communicate & Reflect' phase is important in this respect as a first step to less guide inquiries. Around these basic scenarios, you 'll find more challenging 'open' scenarios that can lead to open and less guided inquiries. When you use these as as 'entrance' points, be aware of the fact that these require more background from your students both in knowledge as also in inquiry skills. The scenarios are quite written out for the teacher and it is up to you to decide how much or how less scaffolding you give to your students in these. We give a description of activities that students can do by using iMuSciCA's workbench. Therefore, the inquiry path can give more degrees of freedom to students.

In upper secondary educational scenarios, students have to deal with concepts of Physics, Mathematics and Music in depth, employing their analytical skills and using their outcomes to reinforce their core STEM knowledge. Throughout their investigations the students learn how to fit functions, how to control variables for multivariate functions, how to use alternative methods such as sonifications in order to comprehend basic mathematical and physics concepts among others. In the center we find two 'basic' scenarios:

  - *Investigating the monochord*: which contain basic concepts of the factors that influence the pitch of a string instrument. These factors are length, tension and density per length. These insights are used in other scenarios to construct an instrument with a desired pitch.
  - *Timbre and Power Spectra*: contains basic concepts of how a complex wave consists of a superposition of pure sine waves. This determines the tone colour and these insights are needed in other scenarios to construct an instrument with a desired timbre.
- Around these basic scenarios, you 'll find more challenging scenarios like:
  - *Instruments of speech*: where students analyse the harmonic content of their voice and create instruments with comparable harmonic content.
  - *Let us hear Thales theorem*: where students divide by means of Thales theorem a length in integer proportions. They bring these proportional lengths over to a monochord.

- *The house of Chords* and *Play Sectio Canonis*: students discover how the mathematical proportions are used as musical proportions that built musical consonance and dissonance. They discover how chords are built with these harmonic musical proportions.
- *Listen to your Math*: students learn about mathematical functions using the technique of sonification and learn to recognize these functions using the sound characteristics of them.

For instance the scenario *Instruments of Speech* uses skills and insights of both *Timbre-Power Spectra* as from *Investigating the Monochord*. Moreover if some students of upper secondary are not acquainted with the basics of waves and sound, they can always at their own pace recall these basic insights from the scenarios from Lower Secondary like *Sound and Tone* and *Standing Waves and Resonant Frequencies*.

The Educational Scenarios of iMuSciCA presented in Table 2.2.1 have been adapted and optimised several times following the feedback of teachers and students during the Pilot Phase B1, which lasted from April to July 2018. In addition, as a result of Teacher Trainings (TTs) given by UCLL and EA many parts of these Educational Scenarios have been further optimised and co-created with teachers.

2.3. iMuSciCA Scenarios Co-Created by Teachers during the Summer School 2018

This Section describes the Educational Scenarios developed by teachers in the framework of the iMuSciCA Summer School which took place in Marathon, Greece in July 2018. Throughout this 5-day long training experience, teachers from all around Europe were trained by the iMuSciCA experts on the Pedagogical Framework, on the core enabling technologies, i.e. the workbench (and the contained activity environments and tools) and on the Educational Scenarios (and the related Lesson Plans) of iMuSciCA.

Fig. 2.3.1.: Impressions from the Teacher Training during the iMuSciCA Summer School 2018

After completing their training, the participating educators were working in small mixed groups involving at least one music and one science teacher in order to draft their own Educational Scenarios. In order to facilitate the community building effort and the maximum outcomes of the cooperation between teachers as well as with the iMuSciCA experts in the co-creation of iMuSciCA Educational Scenarios, the teachers finally joined the virtual online community of the iMuSciCA Summer School 2018 hosted on the Open Discovery Space (ODS) portal.

Fig. 2.3.2.: Online Community of the iMuSciCA Summer School 2018

The teachers drafted their Educational Scenarios, which were then uploaded to Online Community of the iMuSciCA Summer School 2018. The Educational Scenarios will be continuously updated over the next months.

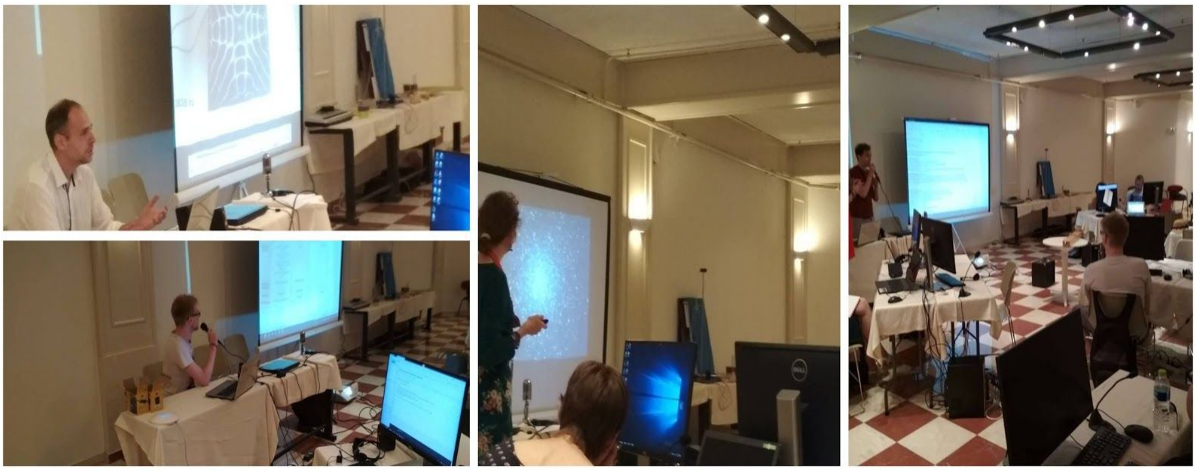

Fig. 2.3.3.: Presentation of Co-Created Educational Scenarios during the iMuSciCA Summer School 2018

Table 2.3.1 summarises the final version of Educational Scenarios fully developed by teachers during the iMuSciCA Summer School 2018.

Table 2.3.1.: Short Description of Educational Scenarios Co-Created by Teachers during the iMuSciCA Summer School 2018 & Relation to the iMuSciCA Workbench

Title	Age group	Description	Workbench tools utilized
Understanding Science through Music	Lower Secondary School	iMuSciCa Scenario exploring sound and sound waves. Different experiments will help students understand how sound is produced and travels through matter (solid, liquid, or gas). They will get acquainted with basic properties (characteristics) of sound: pitch (height), dynamics (loudness). They will experiment with sound waves and their most important properties (frequency, wavelength and amplitude) in order to deepen their understanding of the basic characteristics of sound. At last they will use their experience to design their own musical instrument (invent their own musical scale) and compose their own melodies.	DrawME Tone Synthesizer Visualisations (2D Analyser) Tuner 3D Instrument Design
Sound, Tone & Silence	Lower secondary school	The students open their ears to all different kind of sounds of the environment. They reflect upon sound and silence in a experiential and scientific way. Then they try to produce different kind of sounds themselves and we make a musical composition with all the sounds. Now we do the same exercise, but this time we use tones of the DrawME-tool in the iMuSciCa workbench to create music. After having the experience of creating both music with sounds and tones we investigate the two in a scientific way by measuring the waveforms of both sounds and tones. We conclude by measuring examples of a lot of different examples and put them in one of the two categories.	DrawME
The Chladni Patterns	Upper secondary school	Pupils will observe Chladni patterns, realize their relation to the atomic orbitals of hydrogen atoms and answer questions by utilizing the iMuSciCA suite and an application of augmented reality (AR).	Tone Synthesizer 3D Instrument Design 3D instrument

			performance environment
The Human Ear	Lower secondary school	Students learn about the anatomy of the human ear and its functions. Making a connection between art and science, students investigate how drawings can become musical pieces using the iMuSciCA drawing canvas.	DrawME

Other scenarios by teachers are still under development and can be found in this folder: https://drive.google.com/drive/folders/1xXYE07eNhycsEp0UVDUAdXqIV1VikPjs. It is finally planned that in the next school year 2018/2019 these scenarios will be implemented by the teachers in their classrooms whereas new scenarios will be also produced by them.

3. Conclusions

Completing Educational Scenarios (and Lesson Plans) on a continuously evolving platform such as the iMuSciCA workbench has in itself been a challenge for both, the developers and for the pedagogical partners that shape its reality.

The iMuSciCA educational scenarios incorporate the innovative inquiry based science education across STEAM fields pedagogical framework, using cutting edge technological tools incorporated in the iMuSciCA virtual workbench. In terms of scientific content, the educational scenarios have been designed in a fashion that will be able to address significant student misconceptions in acoustics as well as difficulties in mathematics, engineering and music (please consult D2.3). The transition from one STEAM field to the other, with the potential to start from different points at an inquiry, alongside the utilization of the relevant iMuSciCA workbench tools allow students to approach the content challenges that the scenarios pose in a diverse and artful fashion, helping them to comprehend difficult topics such as standing waves and overtones. In this framework, the iMuSciCA workbench acts as a catalyst through which students explore, ask questions, investigate, analyze and communicate their inquiries.

The feedback from teachers emphasised the high standards they need in order to convert valuable ideas into educational realities. Teachers' contribution towards the process of developing the Educational Scenarios has been therefore crucial in capturing both the educational practice that emerges from their daily educational objectives and from the evolution of the digital Activity Environments and Tools available on the Workbench of iMuSciCA.

The latest versions of the Educational Scenarios of iMuSciCA have been designed taking into account the above parameters. Educational Scenarios do not replace early approaches as they were recorded in view of the first pilot phase, but aspire to feed an evolving creative process towards the next Piloting Phase B2, which does not terminate their improvement, on the contrary it encourages them to develop even further. The approaches presented in this document will continue to evolve beyond the timeframe of the present deliverable as required by the progress of iMuSciCA until the end of its last piloting phase.

References

[1] iMuSciCA D2.3-Initial Educational Scenarios and Lesson Plans for iMuSciCA
[2] iMuSciCA D2.6-Intermediate Educational Scenarios and Lesson Plans for iMuSciCA
[3] iMuSciCA D2.7-Final Pedagogical Framework and use cases by teachers and learners
[4] Hrepic et al (2010). "Identifying students' mental models of sound propagation: The role of conceptual blending in understanding conceptual change." Physics Education Research 6, The American Physical Society.

[5] Linder, C. J. (1992). "Understanding sound: so what is the problem?" Physics Education, 27(5),258- 264.

[4] Arcadi Pejuan, Xavier Bohigas, Xavier Jaen, Cristina Periago: "Misconceptions about sound among engineering students" J Sci Educ Technol (2012) 21:669–685 DOI 10.1007/s10956-011-9356-6

[5] Sükrü Cansiz, Betül Küçük, Tevfik Isleyen: "Identifying the secondary school students' misconceptions about functions" 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.

Appendix 1: The current version of the iMuSciCA workbench

In the iMuSciCA workbench (https://workbench.imuscica.eu) students can perform STEAM-related activities according to the iMuSciCA Pedagogical Framework, Educational Scenarios and Lesson Plans. It includes a set of Activity Environments and Tools to support these activities. The Activity Environments are categorized into three distinct STEAM domains, i.e. Music, Science and Maths and Engineering and Technology. The Activity Environments are launched by clicking on the corresponding icons in the Activity Environments container, while the tools can be activated by clicking on the icons at the right side of the toolbar (Figure A.1.1).

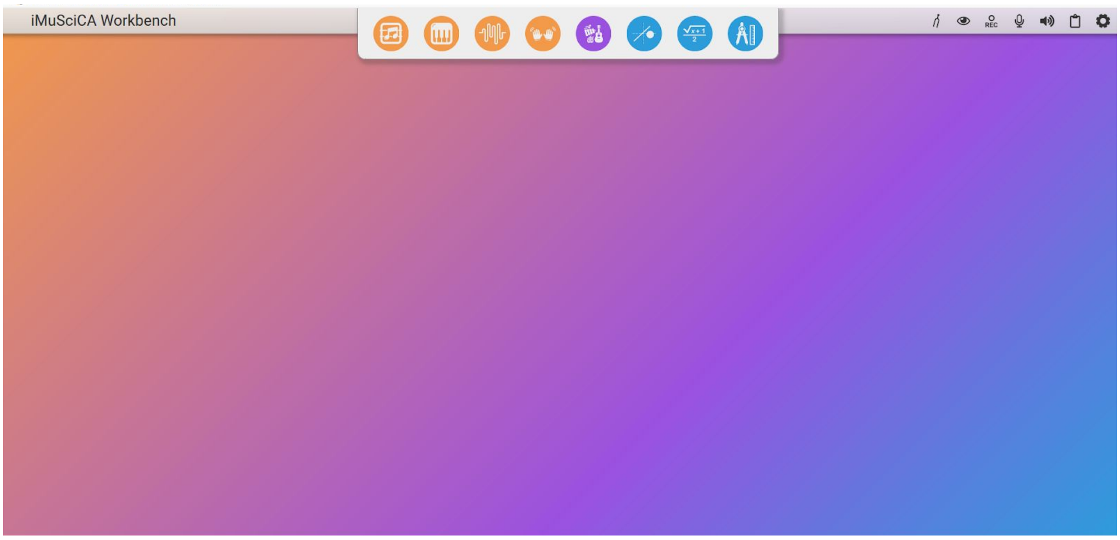

Figure A.1.1.: The iMuSciCA Workbench with Activity Environments (*in the center*) and Tools (*on the right side of the toolbar*)

The activity environments are colour coded according to the STEAM domain as follows:

Music (■)

DrAwME: The Musical Whiteboard

The Drawing Canvas for Music Creation (DrAwME) provides a unique way to interconnect drawings on a canvas with sounds. The y-coordinates of the canvas corresponds to the frequency of the sound, while the colour of the drawing pen specifies to the timbre of the sound. The sound is generated while the user draws on the canvas, and it can be played back using the play button, with the x-coordinates representing time that unfolds from left to right and play the various frequencies (y-coordinates) of the drawing.

Performance Sampler

The Performance Sample Sequencer allows students to work on a recording obtained from the interactive musical instrument performance activity environment or from the microphone. Stored recordings can be imported in audio form and the student can select segments from the recording and rearrange these samples in a matrix and play the sequence of samples by controlling the tempo and time signature parameters. The user can also store her/his composition and share it with other students, generating the conditions for co-creation.

Tone Synthesizer

The Tones Synthesizer allows students to explore timbres as a composition of multiple sinusoidal components. Students can combine sinusoidal elements by adjusting the amplitude and frequency of each, listen to individual component or composite sound, and visualize the individual component or composite waveform.

3D Instrument Interaction

In this environment the student can load and play customized virtual instruments, previously designed in the 3D Musical Instrument Design activity environment. Depending on the virtual instrument, students can use their hands (Leap motion sensor) and their arms/body (Kinect sensor) to interact with the virtual musical instrument and their actions are translated into events that trigger the sound generating engine. The performance can be stored and re-played to be used in other tools (visualization, sample sequencer, analysis).

Engineering and Technology (■)

3D Virtual Instrument Design

In this environment, students can load one of the four pre-designed templates of virtual instruments -a monochord, a guitar, a membrane (circular or square) and a xylophone- can adjust various parameters of the musical instruments, such as for example the body and string length, the string tension, the string radius, the string material of the monochord and listen to the sound they produce. Students can save their designed instruments and load them in the performance interaction activity environment or share them with their classmates.

Science and Maths (■)

Sonification

In this environment, the students can design geometric curves either by selecting from a list of predefined set (lines, circles, ellipses, parabola, etc.) or by drawing by hand the geometric shapes on the canvas that are automatically recognized. These shapes can be played back in a similar manner as in the DrAwME activity environment.

Math Editor

In this environment, the student can entry a math equation either by using the icons of the editor or by handwriting the equation on a canvas that is automatically converted to an electronic form that can be interpreted by other environments. The equations can be copy/pasted to another activity environments such as the sonification of graphs.

Geometry & Algebra

In the geometry and algebra activity environment, students can use a large range of tools suitable for mathematical and geometry design and analysis.

Furthermore, in the iMuSciCA workbench, the student has at her disposal a number of tools that can be activated within an activity environment as follows:

Music tools

The user can select to activate one of the following music tools: (a) a metronome, (b) a pitch wheel and (c) a tuner.

Visualizations

The user can select to activate one of the following visualizations: (a) a 2D time and frequency domain, (b) the snail, a sound visualization based on the scales and notes aligned in spectrally active zones around a spiral and (c) a 3D spectrogram.

Recording

This tool allows the user to activate the sound recorder. The source of a sound can be either an activity environment of the workbench and/or the microphone.

Microphone

This tool allows the user to activate/deactivate the input from the microphone.

Volume

This tool allows the user to adjust the volume of the audio production.

Clipboard

This tool allows the user to have access to various objects that are copied in the clipboard from the various activity environments. S/he can select an object that is copied from an activity environment and paste it in another one.

Settings

This icon allows the user to have access to the global settings, e.g. for switching to another language (currently are supported 5 European languages).

Appendix 2: The EA Students' Summer Camp scenario overview

Introduction

In the iMuSciCA Summer Camp educational scenario we describe the interplay between Science, Technology and Music in the creation and performance of musical instruments. A group of 14-16 year old students learn and experiment with fundamental characteristics of sound such as frequency, amplitude and timbre, learn about music and how to compose their own musical piece. Then they create and experiment with their own virtual musical instruments and investigate the parameters that define the properties of the produced sound. After finalizing their instruments, students 3D print them and perform a musical piece using real, virtual and 3D printed musical instruments.

About the Physics and Mathematics of Sound

Students are introduced to the Physics of Sound. What is sound? Is it a wave or something else? How does it propagate? Why can we hear it and what does exactly hearing mean? They learn about fundamental observables of sound such as frequency and amplitude and they experiment with them in order to obtain deeper understanding of the science behind it.

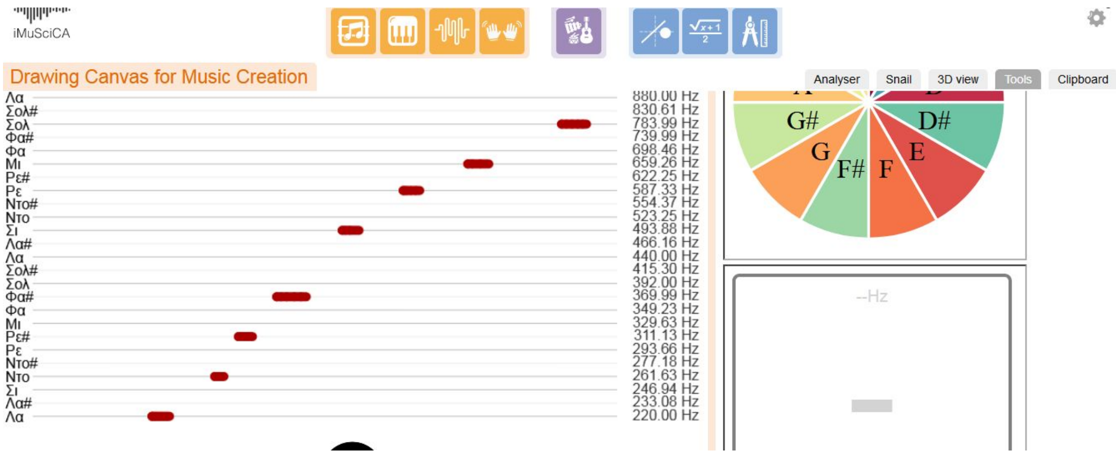

Figure A.2.1: Learning about frequency of sound using the iMuSciCA workbench.

In the next step of their scientific investigation, the students wonder why do different musical instruments sound differently. They experiment with different sounds using the iMuSciCA workbench, sounds generated by them as well as sound produced by real musical instruments and get introduced to the concept of musical timbre. They understand that the differences of the sounding bodies influence the sound produced and get introduced to the Physics of Standing waves. They experiment with different tools and understand how we can analyze sound using powerful visualization and analysis tools such as the waveform, the power spectrum or the spectrogram.

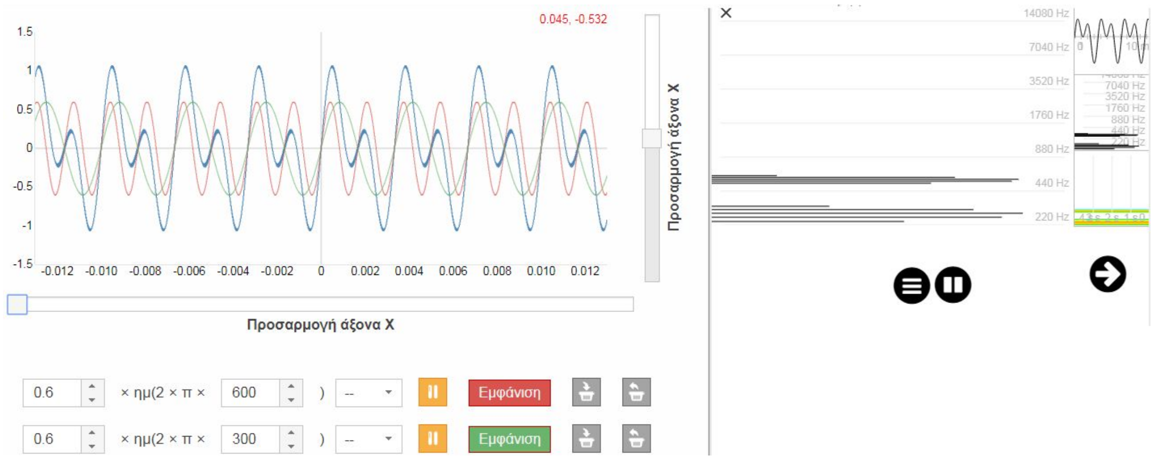

Figure A.2.2: Using innovative visual analysis tools to investigate the harmonic content of sound.

Figure A.2.3: Learning about timbre of sound using different musical instruments and analyzing their sound with the iMuSciCA workbench tools.

About the Music of Physics and Mathematics

Students are introduced in the idea of understanding music as a result of acoustics. Why do we like certain aspects of listening or why do we define others as repellent? Students are introduced into the mechanisms of making consonances pleasant to the ear and the way music is produced using physical instruments. They explore the fundamental steps for defining the notes of the musical scale and experience the logical steps of the Pythagoreans dividing the monochord.

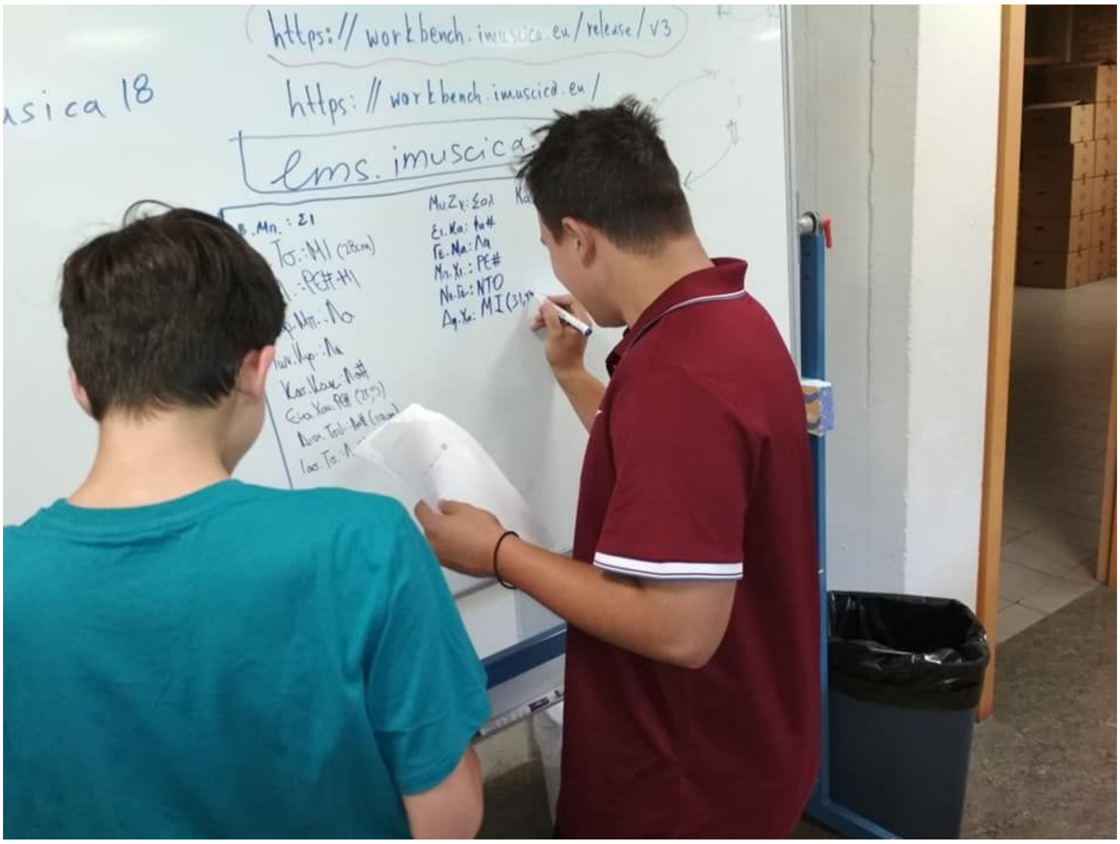

Figure A.2.4: Students learn about notes and design their own math and physics inspired musical piece

Elements of musical praxis: Compose your own musical piece

The most important aspect of a creative activity is collaboration. Musicians understand collaboration as musical “sym-praxis”. By understanding the fundamental aspects of music making through consonance, the iMuSciCA summer camp succeeded in bringing together students with music background along with students that defined themselves as more interested in science. Students were introduced in basic elements of musical praxis which allowed them to form different groups that collaborate together. Writing a melody that comes out of virtual, 3D printed and physical instruments was a challenge that the students had to overcome using the iMuSciCA tools.

Figure A.2.5: Students collaborate to create their final musical synthesis

Create and experiment with your own virtual musical instruments

Students investigate the sound produced by musical instruments. They wonder which parameters influence the sound produced and use the iMuSciCA workbench to experiment with virtual musical instruments such as the monochord. They investigate the influence of string length, tension, radius and material on the sound pitch and experiment to define the mathematical relationship describing the sound frequency as a function of these parameters: Mersenne's Law.

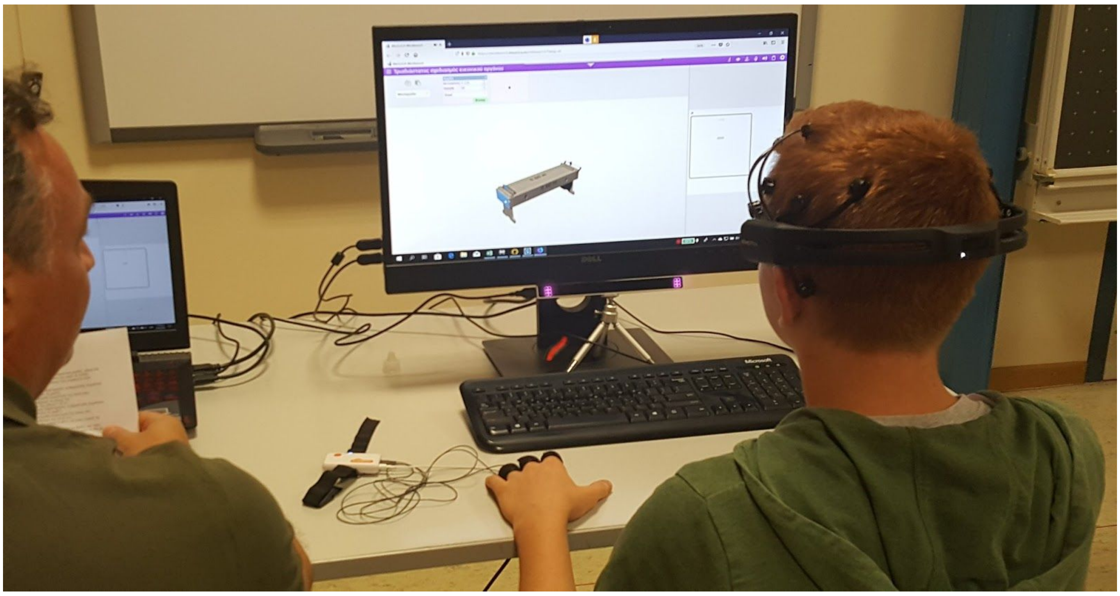

Figure A.2.6: Tracking students' progress using biometric data as they work on specific problem solving tasks.

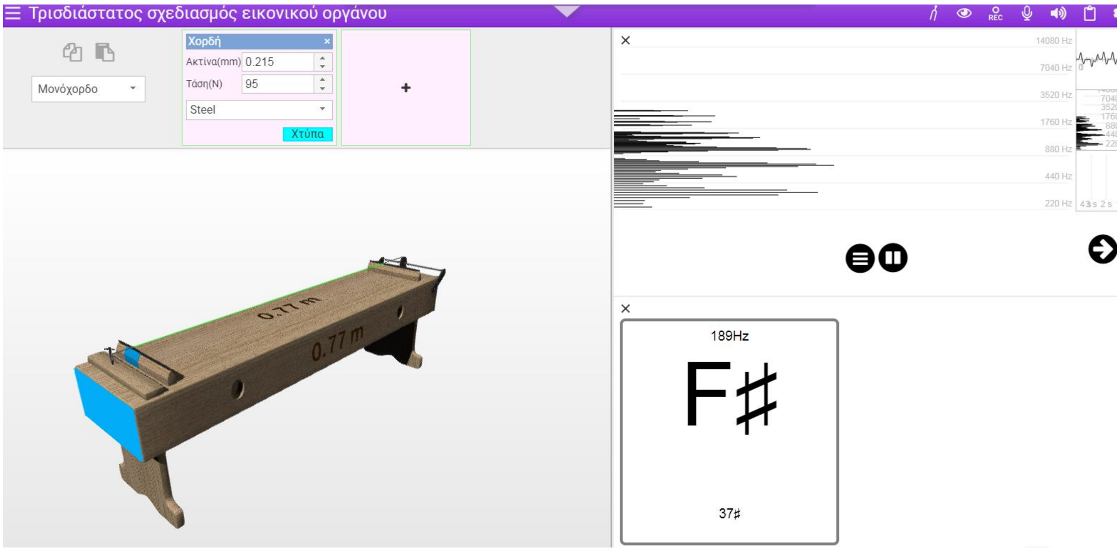

Figure A.2.7: Students investigate the relationship between the frequency of the produced sound, with respect to different parameters, of virtual musical instruments.

They continue their investigation studying the sound pitch of various other musical instruments with respect to their design parameters.

But what happens when a string is divided in the fundamental proportions? How Thales' Intercept Theorem helps students define the ratios of musical notes? These were just a few of the questions that form the core knowledge for musical tuning that kept numerous creative musicians, scientists and music theorists engaged for centuries since even today. Students made the basic steps for understanding Sectio Canonis not only as part of Geometry curriculum but as a living multimodal interactive experiment.

Figure A.2.8: Students prepare and design their virtual musical instruments which will be 3D printed.

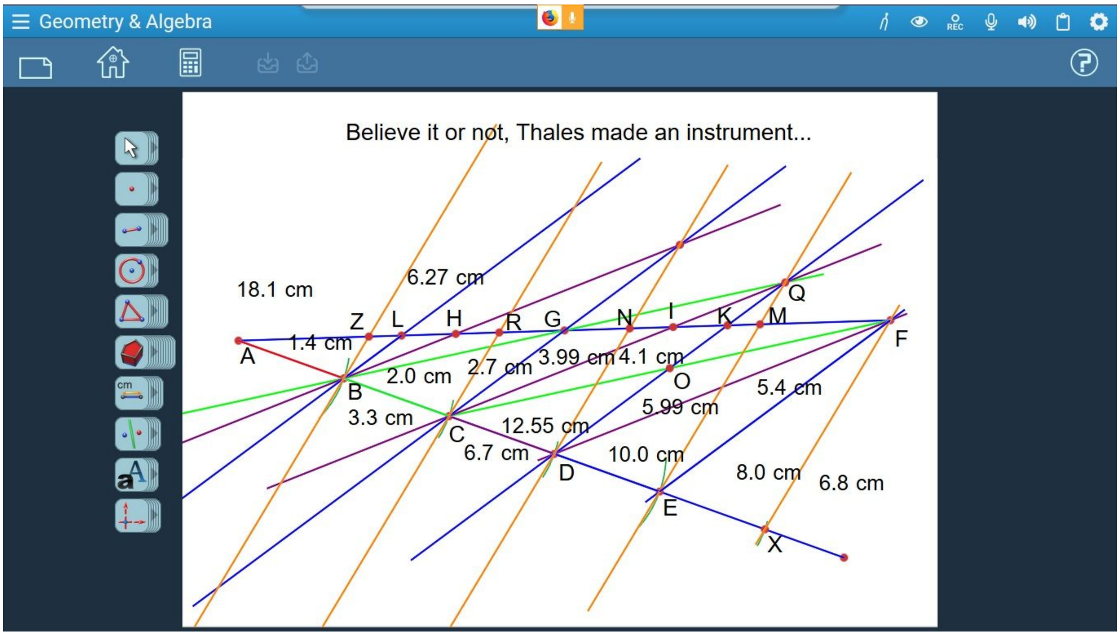

Figure A.2.9: Using the iMuSciCA Geometry and Algebra tools to learn how to divide a string in equal proportions using Thales' Theorem.

3D print your virtual musical instrument

Students experiment with 3D printed replicas of a flute a bec without toneholes but with moveable parts. They define their different acoustical aspects by measuring their behaviour and then they printed their own versions according to their own analysis. The instruments selected were printed out during the summer camp and they became part of the final musical performance.

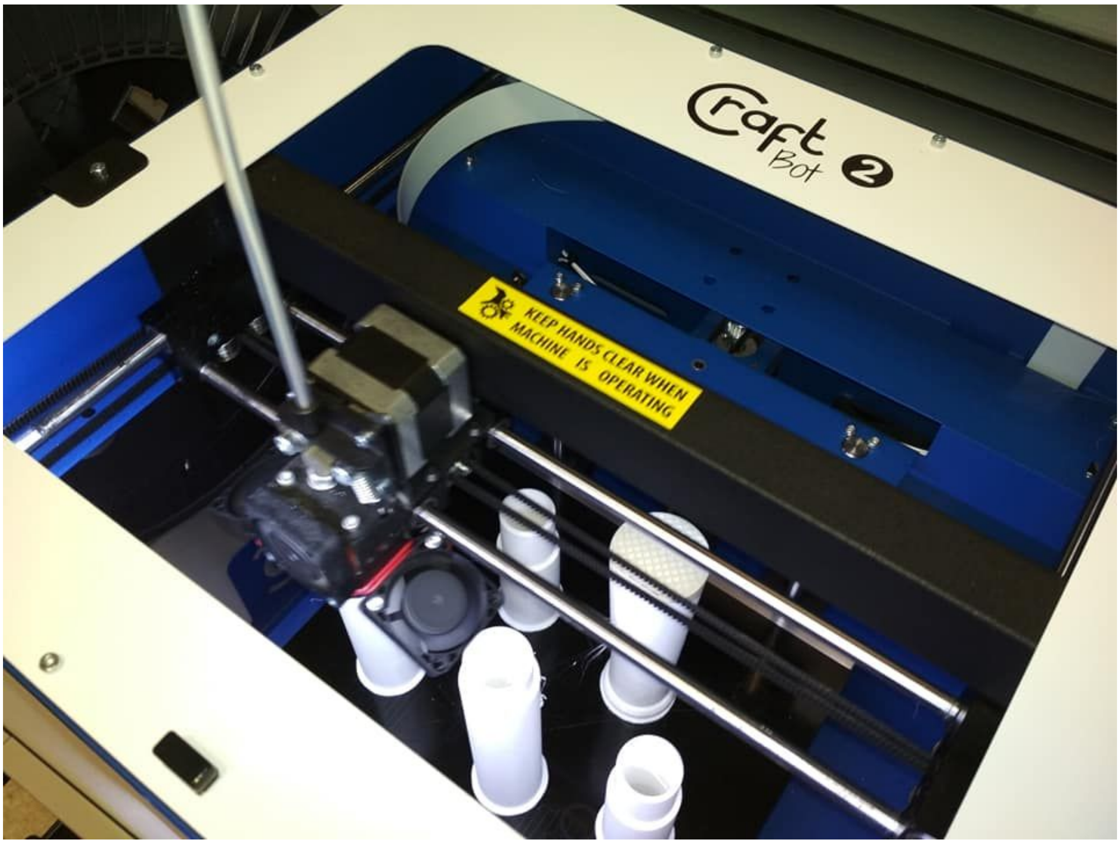

Figure A.2.10: 3D printing student- designed musical instruments.

Perform using virtual, 3D printed virtual and real musical instruments

The result of the intense five-day experiment was a musical happening that took place during the last day of the summer camp. Students divided in groups defined sequence of notes with equal duration forming musical motives as cluster of notes. Performed by all kinds of instruments: virtual, 3D printed, physical, the piece was directed by the music teacher as a result of group effort.

Figure A.2.11: Students rehearse their final musical synthesis.

Figure A.2.12: Students perform their final musical synthesis with virtual musical instruments (left) using the iMuSciCA virtual instrument performance environment, 3D printed musical instruments (center) and real musical instruments (right).