



## Interactive Music Science Collaborative Activities

### Team Teaching for STEAM Education

## Deliverable 2.7

### Final Pedagogical framework and iMuSciCA use cases by learners and teachers

Date:	26/07/2018
Author(s):	Renaat Frans (UCLL), Erica Andreotti (UCLL), Mieke Schuermans (UCLL)
Contributor(s):	Petros Stergiopoulos (EA), Manolis Chaniotakis (EA), Daniel Martín-Albo (WIRIS), Vassilis Katsouros (ATHENA), Colette Laborde (CABRI), Pierre Laborde (CABRI), Marcus Liwicki (UNIFRI), Robert Piechaud (IRCAM), Carlos Acosta (LEOPOLY), Jeroen Op den Kelder (UCLL), Jeroen Vanesser (UCLL)
Quality Assuror(s):	Colette Laborde (CABRI), Evita Fotinea (ATHENA)
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
Description:	Report on the final pedagogical framework and the iMuSciCA use cases for team learning/teaching by learners and teachers. This document provides a pedagogical guide for teachers working with the iMuSciCA workbench and scenarios.



H2020-ICT-22-2016 Technologies for Learning and Skills

**iMuSciCA** (Interactive Music Science Collaborative Activities)

Project No. 731861

Project Runtime: January 2017 – June 2019

Copyright © iMuSciCA Consortium 2017-2019

# Executive Summary

This deliverable describes the final iMuSciCA pedagogical framework and iMuSciCA use cases by learners and teachers and is a further development of deliverable [D2.1 - Initial iMuSciCA pedagogical framework and iMuSciCA use cases by learners and teachers](#) and [D2.4 - Intermediate iMuSciCA pedagogical framework and iMuSciCA use cases by learners and teachers](#). This deliverable is written in the form of an 'iMuSciCA pedagogical guide for teachers'.

This pedagogical guide is the result of the collaboration between iMuSciCA pedagogical and technical partners: pedagogical partners developed pedagogical scenarios and lesson plans, described in this document, in which the workbench tools (developed by the technical partners) are implemented in a pedagogically meaningful way. Of course, this document also includes the results of the intensive piloting performed during the project lifetime in the schools of the three piloting countries (Belgium, Greece, France). In particular the feedback of the participating teachers, collected during teacher training courses and during piloting lessons in schools, was elaborated and included in the updated versions of the scenarios and of the workbench. Furthermore, the feedback of teachers and the results of piloting on students (collected via observations, questionnaires, focus groups with students and teachers) was of great help to write this pedagogical guide. Many parts of this document are indeed based on that feedback and on the collected piloting data: in particular [chapter 3](#) 'How to use iMuSciCA's Learning Environment and scenarios' and 4 'Concepts in the iMuSciCA scenarios' are written specifically to respond to teachers' and pupils' questions and reflections. Of special interest in this sense are the parts dedicated to:

- the pitfalls and suggestions while implementing iMuSciCA in your class, specifically written based on the observations during piloting lessons);
- to the concept maps developed to respond to a teachers quest for more clarity about the concepts treated in the iMuSciCA scenarios.

For more details about the final iMuSciCA scenarios see deliverable *D2.8 Final Educational Scenarios and Lesson Plans For iMuSciCA*. For the results of the piloting phase A see deliverable *D6.2 Interim Report On Teacher's Feedback And Pilot Testing In Schools*. The results of piloting phase B and of the teacher trainings are foreseen for the future deliverables of work package 6.

This document is in itself a new product of the iMuSciCA pedagogical team, with the support of the technical team. Being dedicated to teachers, it contains all the work done by the team since the start of the project and it includes the following main new developments compared to D2.4:

- Final description of iMuSciCA's STEAM Pedagogy Rationale, including the concept of 'Subtle shift towards more genuine inquiry' (compared to the initial 'From guided to pen inquiry').
- Final convention (agreed abbreviations) for identifying the STEAM fields in the iMuSciCA scenarios: based on reactions of teachers.
- Description of the iMuSciCA learning environment (Learning Management system and workbench) dedicated to teachers.
- Updated description of iMuSciCA learning paths for both lower and upper secondary.
- Ideas on how to implement the different STEAM points of view in the lesson hours and a list of pitfalls and suggestions while implementing iMuSciCA in the class, based on the observations during piloting and on teachers' reactions.
- Elaboration of concept maps in the iMuSciCA scenarios.

- Final iMuSciCA use case scenario.
- Five appendices with more details about: Overview of the scenarios, Concept maps for each scenario, iMuSciCA's IBSE pedagogy, How to connect iMuSciCA's to the national curricula in France, Belgium and Greece, Support for using the iMuSciCA workbench (guidelines).

Version Log			
Date	Version No.	Author	Change
7-06-2018	0.1	Renaat Frans (UCLL), Erica Andreotti (UCLL)	Initial structure
19-06-2018	0.1	Renaat Frans (UCLL), Erica Andreotti (UCLL), Mieke Schuermans (UCLL)	Initial content
6-07-2018	0.2	Petros Stergiopoulos (EA), Manolis Chaniotakis (EA)	Added contributions
9-07-2018	0.3	Erica Andreotti (UCLL)	Sent to reviewers
10-07-2018	0.3	Evita Fotinea (ATHENA)	First Review
10-07-2018	0.3	Erica Andreotti (UCLL), Renaat Frans (UCLL)	Responses to reviewers
11-07-2018	0.3	Colette Laborde (Cabri)	Review
12-07-2018	0.4	Erica Andreotti (UCLL), Renaat Frans (UCLL), Jeroen Op den Kelder (UCLL)	Responses to reviewers
27-07-2018	1.0	Vassilis Katsouros (ATHENA)	Submission to the EU

## Disclaimer

This document contains description of the iMuSciCA project findings, work and products. Certain parts of it might be under partner Intellectual Property Right (IPR) rules so, prior to using its content please contact the consortium head for approval.

In case you believe that this document harms in any way IPR held by you as a person or as a representative of an entity, please do notify us immediately.

The authors of this document have taken any available measure in order for its content to be accurate, consistent and lawful. However, neither the project consortium as a whole nor the individual partners that implicitly or explicitly participated in the creation and publication of this document hold any sort of responsibility that might occur as a result of using its content.

This publication has been produced with the assistance of the European Union. The content of this publication is the sole responsibility of iMuSciCA consortium and can in no way be taken to reflect the views of the European Union.

**iMuSciCA is an H2020 project funded by the European Union.**

## **TABLE OF CONTENTS**

<b>Executive Summary</b>	<b>1</b>
<b>Introduction</b>	<b>7</b>
<b>1. iMuSciCA's STEAM Pedagogy Rationale: connecting hitherto unconnected fields on an innovative manner</b>	<b>8</b>
1.1 Description of STEAM innovative pedagogy	8
1.1.1 iMuSciCA's innovative interdisciplinary pedagogy	8
1.1.2 iMuSciCA's new Inquiry Learning across STEAM fields	9
1.1.3 Subtle shift towards more genuine inquiry	10
1.1.4 Collaborative and co-creative learning: in different fields, each fostering the other.	11
1.1.5 21st century skills: across different STEAM-fields	11
<b>2. The iMuSciCA Learning Environment</b>	<b>13</b>
2.1 The iMuSciCA workbench	13
2.1.1 The iMuSciCA activity environments	13
2.1.2 The iMuSciCA Tools	15
2.1.3 Ready to use basic scenarios for lower secondary	16
2.2 The iMuSciCA Learning Management System (LMS)	17
<b>3. How to use iMuSciCA's Learning Environment and scenarios</b>	<b>18</b>
3.1 iMuSciCA learning paths	18
3.1.1 Structure of scenarios dedicated to lower secondary	18
3.1.2 An example of an 'open' scenario	19
3.1.3 Structure of scenarios dedicated to upper secondary	20
3.2 Meta-info given for each scenario	21
3.2.1 Ready to use Activity Books	23
3.3 How to implement the different STEAM points of view	23
3.4 Pitfalls and suggestions while implementing iMuSciCA in your class	24
<b>4. Concepts in the iMuSciCA scenarios</b>	<b>26</b>
<b>5. An iMuSciCA Use Case Scenario: Synthesize the timbre of your preferred musical instrument</b>	<b>27</b>

5.1 A motivating scenario: Synthesize the timbre of your preferred musical instrument	27
5.2 Concepts & skills across fields: discovering a more complete picture	29
5.3 Possible paths for 'Synthesize the timbre of your preferred musical instrument'	30
<b>Conclusion</b>	<b>33</b>
<b>References</b>	<b>34</b>
<b>Appendix 1 - Overview of the scenarios</b>	<b>36</b>
<b>Appendix 2 - Concept maps</b>	<b>43</b>
<b>Appendix 3 - iMuSciCA's IBSE pedagogy</b>	<b>47</b>
<b>Appendix 4 - How to connect iMuSciCA's to the national curricula in France, Belgium and Greece</b>	<b>53</b>
<b>Appendix 5 - Support for using the iMuSciCA workbench</b>	<b>58</b>

## LIST OF ABBREVIATIONS

Abbreviation	Description
LCMS	Learning Content Management System
WP	Work Package
ATHENA	ATHENA RESEARCH AND INNOVATION CENTER IN INFORMATION COMMUNICATION & KNOWLEDGE TECHNOLOGIES
UCLL	University College 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
STEM	Science, Technology, Engineering and Maths
STEAM	Science, Technology, Engineering and Maths combined with Arts
IBSE	Inquiry Based Science Education
URL	Uniform Resource Locator

# Introduction

Up till now Inquiry Based Science Education (IBSE), as the name states, was mainly used in science education or at the utmost in single, specific fields like music or engineering, but then as separated subject matter inquiries (see for instance Pedaste et al., 2015). Most students nowadays in school see hardly ever the relation between concepts or skills that are being taught to them in different fields or subject matters (Honey et al., 2014). Moreover, as presented in [appendix 4](#), the standard curriculum in the three iMuSciCA piloting countries (France, Greece, Belgium) does not include a pedagogy connecting Music with Science and Engineering. In this way iMuSciCA introduces an innovative pedagogy.

***Example:** Students in school learn about waves and superposition in physics and mathematics, but in standard curricula they don't connect this to what they are experiencing in music: melody, timbre or harmony. The iMuSciCA pedagogy instead makes those specific concepts and the connections between them explicit. The same goes for engineering, which is even typically absent in many national curricula: in iMuSciCA even the engineering concepts are made explicit. For example, while designing their own instrument in the iMuSciCA 3D Virtual Instrument Design, engineering concepts are made explicit and students experience that concepts of maths and physics are at stake as well.*

In this document you will find out in which many ways iMuSciCA focuses on these intertwinings: interdisciplinary concepts and skills, inquiries across fields, stages from guided to unguided, collaborative and co-creative learning and 21st century skills.

In [section 1](#) you will discover more about the iMuSciCA pedagogy and how it connects concepts in different fields. In [section 2](#) and [3](#) you will discover what makes up the iMuSciCA Learning Environment, i.e. a workbench where you can find different activity environments and tools, pedagogical guided scenarios to get inspiration on how to use the iMuSciCA workbench in the classroom and some ready-to-go template scenarios made in the Cabri Express environment who will start a mouse-click away. You will also find there some suggestions how to avoid pitfalls which are based on the experience of the writers of this document while piloting the iMuSciCA Learning Environment. In [section 4](#) you will discover how the concepts of the different fields are made explicit and you will find suggestions to bring the concepts in your lessons. In [sections 5](#), you will find an iMuSciCA use case scenario you can deploy in your classroom. It is about 'synthesize the timbre of your preferred instrument'. You will discover that the same scenario can be deployed following a 'safe' guided pathway (guided inquiry) or following a more open, adventurous approach and start directly by playing with one of the iMuSciCA activity environments.

Through the combination of this interdisciplinary pedagogical methodology and of state of the art educational technological tools, developed by the iMuSciCA consortium, we want to bring this innovative interdisciplinary pedagogy in schools. This pedagogical guide wants to give support to teachers implementing the iMuSciCA Learning Environment and pedagogy in their classroom. The information reported in this document is the result of an intensive piloting and collaboration with teachers in schools in France, Belgium and Greece. Based on these experiences in the piloting schools the iMuSciCA Learning Environment has been continuously improved. Even more than this, the iMuSciCA Learning Environment and more specifically the scenarios, are 'living' tools, which will keep evolving and of course can be adapted by the users according to the specific situations and needs.



# 1. iMuSciCA's STEAM Pedagogy Rationale: connecting hitherto unconnected fields on an innovative manner

## 1.1 Description of STEAM innovative pedagogy

iMuSciCA introduces a contemporary teaching methodology at the intersection between art and science by bringing the following 5 highlights into the classroom:

1. **iMuSciCA's innovative interdisciplinary pedagogy**
2. **iMuSciCA's new Inquiry Learning across STEAM fields**
3. **iMuSciCA's subtle shift towards more genuine inquiry**
4. **Collaborative and co-creative learning:** in different fields, each fostering the other.
5. **21st century skills:** across different STEAM-fields



**Figure 1:** Innovative features of iMuSciCA's pedagogy.

### 1.1.1 iMuSciCA's innovative interdisciplinary pedagogy

The basic idea of iMuSciCA is to connect hitherto unconnected fields. In the iMuSciCA pedagogy the STEAM fields are connected through the concepts: when working with the iMuSciCA workbench (see [chapter 2](#)) and scenarios (see [chapter 3](#)), pupils start from the concepts in one discipline and connect to corresponding concepts in the other disciplines. The concepts and the connections are also made

explicit to students: in order to make these connections visible, concept maps were developed for the scenarios and lesson plans (see [chapter 5](#)).

In iMuSciCA we use the following convention to identify the STEAM fields, which differs from the more common conventions used for STEM and STEAM :

- 'S' stands for science and mathematics
- 'A' stands for music (the Art component)
- 'E' stands for engineering and technology

This convention which uses three fields, i.e. grouping maths with science and engineering with technology, was established as a more convenient way to elaborate the iMuSciCA scenarios and the workbench. However, the teacher can always make explicit to the learner whether they are doing maths instead of science, or engineering instead of technology. The 3 above letters are consequently used in the iMuSciCA scenarios and they correspond to the three colours of the workbench (see [section 2](#)). It is up to the teachers' team to decide which activities to perform in which lessons, depending on the class, the curriculum, etc. For example teachers can decide to perform scientific activities in science lessons and musical activities in music lessons. For the same reason it is ideally a team of teachers that work together to bring iMuSciCA in the class, in different lessons per subject matter or by participating all together in the iMuSciCA lessons (co-teaching). As described in [chapter 3](#) teachers are also free to adapt the scenarios or even to develop their own scenarios, so not all the proposed activities in all the STEAM fields are expected to be performed in the class. However a good balance between scientific, musical and engineering activities should be endeavored.

### 1.1.2 iMuSciCA's new Inquiry Learning across STEAM fields

iMuSciCA applies Inquiry Based Science Education (IBSE) to STEAM. IBSE was up to now mainly applied to scientific disciplines and in some cases to other disciplines. In iMuSciCA the traditional IBSE phases are broadened as they are applied *across* the different STEAM fields. The classical IBSE phases acquire therefore a different meaning in each specific field. The five inquiry phases in iMuSciCA are:

1. Engage (Wonder, Ask Questions, Explore, Observe– Identify Problems, questions and chances; Relate to Background Knowledge).
2. Imagine (Identify relevant variables to investigate – Identify Relevant Solutions to use; Use your imagination and make hypothesis – Choose potential solutions).
3. Create (Plan the Investigation / Design the Prototype; Carry out Investigation / Build the Prototype).
4. Analyse (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).
5. Communicate and reflect (Communicate Results and Conclusions/ Communicate the Product, perform; Reflect on Feedback and incorporate in further process).

These are explicitly mentioned for each activity in the scenarios in order to trigger the awareness of teachers and students concerning the learning process they go through.

However, iMuSciCA tries to reflect the open way in which real investigation occurs: as history of science shows, inquiry often follows rather unexpected paths (Matthews, 1994; Bartos & Lederman, 2014; Lederman & Nies 1997). Therefore iMuSciCA considers the above inquiry phases **as a model**. This implies that the phases do not necessarily follow a standard sequence: variation and loopholes (sometimes certain phases come back a few times before going further).

These somehow unexpected paths perfectly reflect the sometimes quite dazzling inquiry paths that occur in the real STEAM world.

In [appendix 3](#) you find more details concerning the meaning of the inquiry phases in the different STEAM fields.

### **1.1.3 Subtle shift towards more genuine inquiry**

iMuSciCA's makes a 'subtle shift' towards more genuine inquiry possible:

1. students can choose their own learning path: different starting points possible, you can start using the workbench going out from different questions
2. teachers can alter the degree of scaffolding given to their students: a very crucial factor to let students grow towards more genuine and independent science inquiry (Rankin, 2011; Tiberghien, A., 2000).

#### **Choose your own learning path or start with some suggested ones**

Many times, though not always, iMuSciCA will let users start from the experience of music (music is then used as a context). This can lead to a wide variety of inquiry questions. On other occasions, scientific or engineering questions serve as a starting point like, for instance 'synthesize the timbre of your preferred instrument'. Whatever approach you choose, iMuSciCA scenarios give your students a journey through different fields. It gives the chances to connect different fields hitherto mostly left unconnected: music, science and engineering. The context and the tools iMuSciCA provides you with, give way to numerous wonderings and inquiries. This makes iMuSciCA ideal to follow your own learning path. However, if your students are in need of some guiding, you will find some suggestions of possible learning paths under 3.1 iMuSciCA learning paths. We co-created some possible scenarios as lesson suggestions.

#### **Different degrees of guiding and scaffolding**

One of the most frequently discussed topics by teachers is the question of balance between structure and freedom, or the amount of responsibility given to the learner compared with the amount of teacher direction. iMuSciCA is especially suited to implement the so-called "subtle shifts"-strategy in inquiry (Rankin, 2011).

The more you work with iMuSciCA the more it is important that you, as a teacher, can make a subtle 'shift' towards:

- More open-ended questions
- Situations where learners have to formulate hypotheses and propose a way of investigating this themselves (with the workbench tools many possibilities are suggested)
- Though iMuSciCA gives good inquiry questions as a start, it also lets learners gradually choose what to investigate.
- Though data sheets are sometimes provided, leave them out gradually and let learners design their own data sheets. Learn them to report what they think is significant.
- Feed the expectation that learners will have new questions when they're finished, just as scientists do.

However, be aware that the iMuSciCA's pedagogy tries to avoid one of the reported pitfalls in this respect: more open challenging approaches ask for *appropriate scaffolding and guiding* of students especially those with weaker backgrounds. If scaffolding lacks, weaker students tend to have lower learning outcomes than more privileged ones (Kirschner et al., 2006). It is therefore important that you as a teacher remind your students to other more basic scenarios and to needed background information when needed.

You can find help in the concept maps of the different scenarios so that you can see which concepts your students will need (see [appendix 2](#) for the concept maps of each iMuSciCA Scenario). Moreover

in the scenarios last column, you will find more suggestions and also background your students might need when performing the task (see [section 3](#) for the detailed structure of present and other scenarios).

Depending on what your students can take, you can give more or less guiding. It is important that you as a teacher look after your students especially as you want to bring them to more open inquiries. See in [section 3.1](#) iMuSciCA learning paths, how, for different points of entry, students are referred to the appropriate basic scenarios where they can update their prior knowledge. Only then open inquiries make sense.

#### **1.1.4 Collaborative and co-creative learning: in different fields, each fostering the other.**

iMuSciCA's workbench and lesson activities are designed to address many characteristics that are known to support collaborative learning (Kirschner, 2001). These include: active Learning, teaching and learning as shared experiences, student participation in small-group activities, making students reflect and taking responsibility for their learning (Perkins, 2010; Honey & Kanter, 2013; Martinez & Stager, 2013). We will highlight here only the most important points that iMuSciCA's pedagogy is aiming at in relation to co-creative learning.

iMuSciCA involves students in the interdisciplinary field of music, science and engineering. By creating a learning environment where students can deepen one field and discover connections to another, acquisition of knowledge and skills in all fields is supported: Look for instance to the iMuSciCA's concept maps to see which connections are made in iMuSciCA's scenarios ([see section 4](#)) (Tamassia & Frans, 2014; Quigley et al. 2017; Tsupros et al. 2009). Moreover precisely thanks to this rich interdisciplinary environment iMuSciCA give students opportunities to collaborate and co-create together, maybe starting from their favourite angle of approach and giving each individual a complementary role in the learning group or class.

iMuSciCA's small group activities of interdisciplinary nature allow students to take responsibility for part of the activities. For instance, some students can take the lead in a music activity while others can be in charge of coordinating a scientific experiment or later of designing something. Because of the variety of fields and angles of approach that iMuSciCA gives to students, this supports collaborative skills, shared learning experiences and stimulates 'out of the box' thinking and creativity.

iMuSciCA's pedagogy stresses 'communicate and reflect' phases a lot. During these phases it is important that you let students formulate their own assumptions and thoughts and confront their findings and thinking with other peers. Especially in classes with younger children, do these reflections often enough, at least at the end of each class. For older more experienced students, you can wait with reflections and do them only after some more time. But in any case, don't leave them out: these are the privileged moments to discover what your students learned.

Your role as teachers - in iMuSciCA we talk about teachers in plural, since iMuSciCA involves teachers from different backgrounds - is to provide overview, organise reflection and guidance when needed. You can recommend different pathways through different iMuSciCA scenarios while scaffolding student's background and reflection. Only when there is a 'STEAM'-team in your school, a STEAM-pedagogy in class makes sense to the learners as well.

#### **1.1.5 21st century skills: across different STEAM-fields**

As a teacher you know that 21st century skills (Wagner, 2008) are important learning goals and iMuSciCA has translated them into design principles for the iMuSciCA scenarios and lesson plans.

Following Saavedra & Opfer (2012) iMuSciCA used the so-called ‘9 lessons for a 21st century pedagogy’. These include: make things relevant and teach through disciplines, develop thinking skills and encourage learning transfer, learn students how to learn and address misunderstandings directly, use technology to support learning, foster creativity and treat teamwork as an outcome. As was done for the previous paragraph, we will highlight here only the most important points that iMuSciCA’s pedagogy is aiming at in relation to 21st century skills.

Quite an advantage is that iMuSciCA activities can start from different fields and so you can engage students from different perspectives. The context of music ‘resonates’ clearly with students every day experiences and iMuSciCA has therefore the potential to make learning more relevant for your students (Perkins, 2010).

In a classical model of education, teachers are of course restricted to a certain subject matter. This remains the dominant approach in compulsory education in much of the world (OECD, 2009). Typically, students taught in this way do not have much practice in applying their knowledge to new contexts, to solve new problems. The iMuSciCA pedagogy let you overcome typically this shortcoming by giving you a pedagogy that connects different teachers in a STEAM-context of music, science and engineering: it will turn your student’s knowledge and skills more transferable across fields and contexts. Connecting knowledge from different fields helps your students to deepen understanding in any of the three iMuSciCA fields. It is known that learning transfer is hard to achieve and by iMuSciCA you can give your students the needed support and practice (Fogarty et al., 1992; Salomon & Perkins, 1989; Schwartz & Fischer, 2006; Jensen & Nickelsen, 2008; Czerniak & Johnson, 2007). iMuSciCA’ tasks are designed to actively make connections between scientific insights, musical experiences, and engineering designing tasks.

Example: Students in iMuSciCA might for instance start with some lower order skills by plugging numbers into an equation or a table when trying to understand the relationship between frequency and natural tones. But soon they apply this knowledge to another field: for instance while listening to or designing an instrument. So they *reconnect* the scientific relation to another context: the hearing or the making for that matter. This has the potential of making science learning more relevant because they can experience science from different angles.

With the iMuSciCA workbench you can provide your students with a technology environment, where virtual instruments can be tested or designed, where experiments can be performed. So it is an ideal and safe environment to let your students *learn by playing*: mistakes can be seen as opportunities for growth rather than failures (Dweck, 2000). Also creativity, that in some classes might be seen as a fixed characteristic that people either have or not in a certain field, iMuSciCA show the incremental side of it: a ‘through the disciplines’ approach is especially fertile in this sense (Robinson, 2001; Kim & Park, 2012a ; Kim & Park, 2012b; Csikszentmihalyi, 2008; Sternberg, 2006).

iMuSciCA can support a more positive mental model for science learning: you can encourage your students so that intelligence and capacity can increase indeed with effort. Give them opportunities to use the workbench and to investigate new phenomena in the field of science and music. Let one of the premade scenarios inspire you. Adapt them to the needs of your class. Of course your students like any others will have many misconceptions on their way and they will hold onto them until they can discover more coherent explanations based on new experiences or more coherent models (Perkins & Grotzer, 2005). iMuSciCA’s pedagogy confront students’ ‘theory’ every time with practice and evidence not only from music but also from other fields, such as science and engineering. With iMuSciCA’s you can give your students a ‘studio of learning’ in which small groups of students work on a given issue and reflect upon this with their peers and teachers.

## 2. The iMuSciCA Learning Environment

The iMuSciCA Learning Environment consists of two main components:

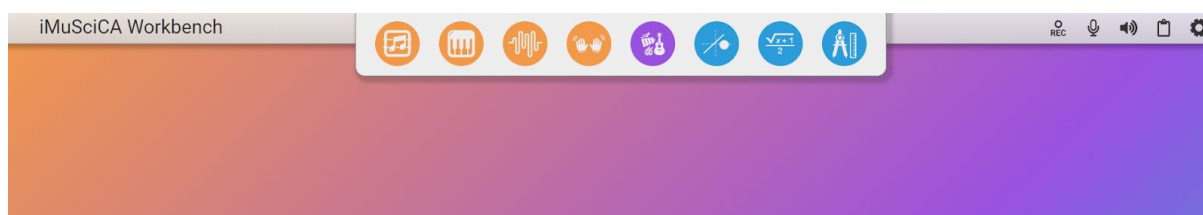
1. The iMuSciCA workbench;
2. The iMuSciCA Learning Management System (LMS), in short the 'Moodle'.

### 2.1 The iMuSciCA workbench

The innovative iMuSciCA Learning Contents are provided to teachers and students in a unified workbench (<https://workbench.imuscica.eu>). The workbench is the place where students can perform STEAM-related activities according to the iMuSciCA STEAM pedagogy and scenarios. It provides a set of *activity environments*, classified according to the different STEAM domains: A for music, S for science and mathematics, E for engineering and technology. A set of *tools* is also provided which can be used to support the learning activities while using the activity environments.

The *activity environments* and *tools* can be launched by clicking on the corresponding button or icons, located at the top of the window (see figure 2).

When following a scenario students and teachers find instructions guiding them to go to the iMuSciCA workbench and perform activities using the *activity environments* and *tools*. When using the iMuSciCA workbench, users produce some data and products which they can save and retrieve the next time they access the workbench.



**Figure 2:** The iMuSciCA workbench landing page with the buttons for the activity environments on the top center and the icons for the tools on the top right.

#### 2.1.1 The iMuSciCA activity environments

The *activity environments* are eight in total and are colour coded according to the domain (A, S, E) they belong to:

- 1) orange for Music activity environments: i) DrAwMe: The Musical Whiteboard; ii) Performance Sampler; iii) Tone Synthesizer; iv) 3D Instrument Interaction.
- 2) purple for Engineering and Technology activity environments: v) 3D Virtual Instrument Design.
- 3) blue for Science and Maths activity environments: vi) Sonification; vii) Math Editor; viii) Geometry & Algebra.

To get an idea about how you can use each activity environment, you can have a look at the created scenarios: see [appendix 1](#) for a complete list of the scenarios and corresponding activity environment and tools used in each of them. The scenarios can be found in a pupils' version, on the iMuSciCA LMS (Moodle). In [appendix 1](#) you will find also direct links to each iMuSciCa scenario.

### **DrAwME: The Musical Whiteboard**

The Drawing Canvas for Music Creation (DrAwME) provides a unique way to interconnect drawings with sounds. The y-coordinates of the canvas specify the frequency of the sound, while the colour of the drawing pen corresponds to the timbre of the sound. The sound is generated while the user draws on the canvas, but it can also be played back using the play button. The x-coordinates specify the time which unfolds from the left to right and play the various frequencies (y-coordinates) of the drawing. While using DrAwMe you may also choose among a number of sound visualization tools. For example you can visualize the sound produced by DrAwME with the Snail tool, which displays music tones around the spectrum of a sound as a “blob” with size and color that depend on the energy and phase shift in the Fourier decomposition.

### **Performance Sampler**

A Performance Sample Sequencer allows students to work on a performance recording, obtained from the interactive musical instrument performance activity environment. Students can explore combinations of segments of their recordings to generate new music. To this end, stored recorded performances can be imported in audio form into the sampler’s interface. The student can then select segments from this performance recording as regions on the waveform and activate those samples on the sampler’s matrix. The user can store the current settings of their composition and share it with other students, generating the conditions for co-creation.

### **Tone Synthesizer**

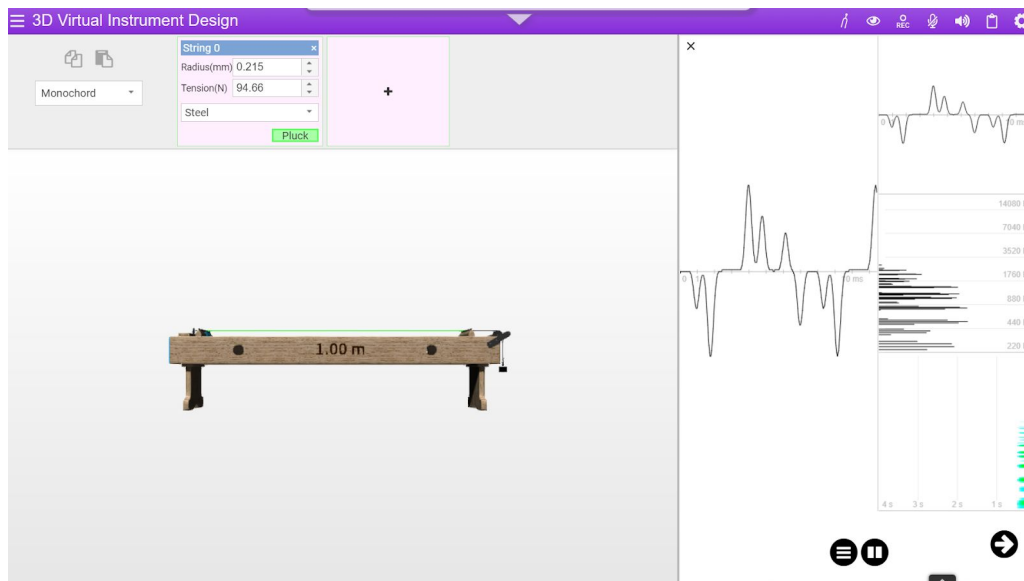
An alternative approach to study sound is provided by the Tones Synthesizer activity environment, which allows students to explore timbres as an addition of multiple sinusoidal elements. Students can listen to the sound produced by up to ten sinusoidal elements combined (summed), change their parameters (amplitude and frequency) and visualize the produced waveform, either as a whole or of each element separately.

### **3D Instrument Interaction**

In activities related to the interactive musical instrument environment, the student can either play pre-set instruments or load customized virtual instruments, previously designed in the 3D Musical Instrument Design. Students can use their hands (Leap-based interaction module) and arms/body (Kinect-based interaction module) 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).

### **3D Virtual Instrument Design**

Virtual music instruments can be designed in the 3D Music Instrument Design environment (figure 3). In this environment, the user can load four pre-designed instruments: a monochord, a guitar, a membrane (circular or square) and a xylophone. Students 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. Students can then listen to the produced sound from the instrument and measure the frequency by using e.g. the visualization tools.



**Figure 3:** The monochord on the iMuSciCA 3D Virtual Instrument Design tool.

### Sonification, Math Editor, Geometry & Algebra

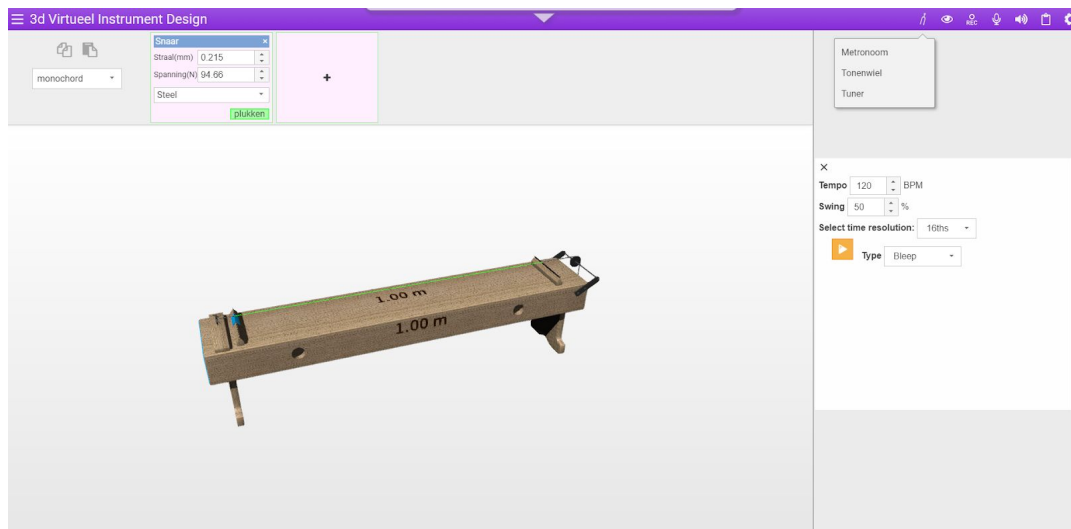
Finally, three scientific and mathematical activity environments are available to students. In the sonification of mathematical expressions activity environment, students can design mathematical equations and geometric curves and let them sound; in the mathematical equation editor, they can write math equations using menus and keyboard or by handwritten recognition; and in the geometry and algebra activity environment, an all-purpose exploratory environment, they can use a large range of tools suitable for mathematical and geometry design and analysis.

#### 2.1.2 The iMuSciCA Tools

A set of useful *tools* is available when users interact with an activity environment. These tools are:

1. **Music tools:** Metronome, Pitch wheel, Tuner; these tools are useful when creating music or in some cases to easily measure the frequency of a played tone.
2. **Visualization tools:** 2D Sound Visualization, The Snail, 3D Sound Visualization; these tools are all very useful to visualize the sound produced by an instrument, a real one or a virtual one on the workbench.
3. **Sound recorder:** it allows to record sound produced by the workbench or real external sounds; it also allows to save the recorded sound, to load a previously saved one and can be used in combination with the clipboard to copy and paste the sound and play it again.
4. **Microphone:** it allows measuring and recording external sounds and it can be activated and deactivated by clicking on the corresponding icon.
5. **Volume:** it allows volume control by a slider appearing when clicking on the volume icon.
6. **Clipboard:** it enables activity environments to transfer content among them.
7. **Settings:** it allows changing some settings, like the language of the workbench.





**Figure 4:** The iMuSciCA workbench view when opening one specific activity environment (in this case the 3D Virtual Instrument Design): on the top left all the buttons of the tools are visible. When clicking on the button of a tool a window appears at the right side of the activity environment (in this case the Metronome is shown).

### 2.1.3 Ready to use basic scenarios for lower secondary

As described below in 3.2.1 two of the developed scenarios for lower secondary are in the form of interactive digital learning books, also called ‘Activity Books’. The activity environments and tools to be used are directly integrated in these digital learning books. When performing a specific activity, pupils can easily get access to the needed iMuSciCA activity environment and tool from the workbench as they are integrated in the same page of the activity (see figure below as an example).

**Figure 5:** Example of the Activity Book of scenario 2.1 ‘the sequence of natural tones where students can interact directly with the workbench for instance here where they can measure the frequencies of natural tones on a thin whistle. They can record and playback.

## 2.2 The iMuSciCA Learning Management System (LMS)

The iMuSciCA Learning Management System (LMS) is the main entry point to the activity environment and it is accessible at <https://lms.imuscica.eu>. This LMS builds on a standard Moodle environment. On the LMS you can find the individual scenarios (in a form that is adapted to learners) and corresponding descriptions, with links to the iMuSciCA activity environments and tools on the workbench, and when appropriate related tests. The LMS is useful to organize and storage the learning activities. Teachers and students need to create a personal account to log in the LMS. Furthermore when users follow a learning content through the LMS, they produce some data (question answers, marks, current progress within an activity, etc.) which are stored in a repository. This way teachers can track the activities of the students and give online feedback. Teachers can use the existing scenarios created by the project team, but also create or adapt the activities in the LMS (see [chapter 3](#)).

## 3. How to use iMuSciCA's Learning Environment and scenarios

### 3.1 iMuSciCA learning paths

The iMuSciCA tools provides your students with many possibilities for inquiries in music, in science and in engineering. Therefore, iMuSciCA is ideal to let your students follow **their own learning path**.

Many different starting points are possible. For instance you can start your inquiry from the experience of music. This can lead to a wide variety of inquiry questions like: 'why do different instruments sound different though playing the same tone?'. On other occasions, scientific or engineering questions serve as a starting point like, for instance 'synthesize the timbre of your preferred instrument'.

Below you can find some suggestions for different learning paths, which are called scenarios, that your students can follow. These **scenarios** were **developed in co-creation** with groups of **teachers** in Belgium, France and Greece. You have to look at these scenarios as possible 'modules', building blocks that can inspire you to form your own curriculum or to let the students discover their own learning path.

The aim of the scenarios is to offer inspiration, support and background information to teachers, while giving them and their students 'choice' among different possible 'paths'. By co-creating the scenarios with teachers in each country, it was possible to adapt these to the national curricula and address specific situations.

We divided the scenarios we developed as suggestions, into two main groups, depending on the age of the students:

- focussing on lower secondary pupils, i.e. 12-15 years old (available in English, Dutch and French)
- focussing on upper secondary pupils, i.e. 14-17 years old (available in English, Greek and partly in Dutch).

You can find an overview of the developed iMuSciCA scenarios in [appendix 1](#) 'Overview of the scenarios'.

#### 3.1.1 Structure of scenarios dedicated to lower secondary

We present in figure 6 below the structure of and the mutual connection between the **scenarios dedicated to pupils of 12-15 years old** of lower secondary level. Indeed the iMuSciCA scenarios do have some pedagogical coherence. As a teacher you can keep this in mind when guiding your students through the scenarios:

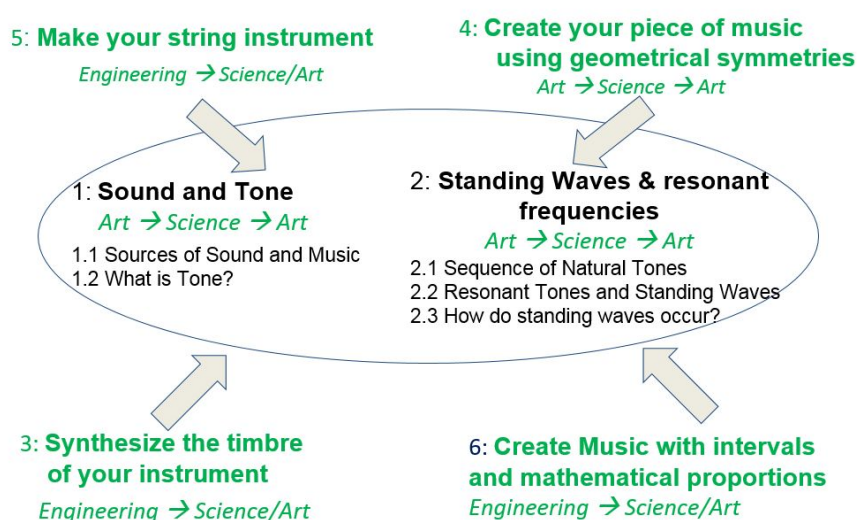
- In the center we find two 'basic' scenarios which contain basic concepts of music, physics and mathematics, e.g. what are the sources of sound and tone, what is a tone, what are natural tones, etc. These two scenarios are built in a quite guided way. They can be a good starting point for those, mostly 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 7<sup>th</sup> and 8<sup>th</sup> grades (12-14 years old), but it can be implemented even in the 9<sup>th</sup> 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.

The idea behind this structure is that teachers can start in their class for instance from an ‘open’ scenario (entrance point into iMuSciCA). This open-end inquiry can stimulate curiosity and interest in students but is quite challenging at the same time. So whenever they are in need of more scaffolding, refer to the basic scenarios, this give them the opportunity update their background knowledge, the understanding of basic concepts, to acquire basic skills discussed or used in these open scenarios. Of course, teachers read all this scenarios as suggestions, as help for you and your students. You are in no way whatsoever obliged to follow these literally, feel free to adapt them or to develop even new lesson ideas. We are always curious to hear something from you.

## Pedagogical Coherence and *STEAM*-pedagogy of the iMuSciCA’s Scenario’s




**Figure 6:** Pedagogical coherence and STEAM fields for iMuSciCA’s lower secondary scenarios.

The structure of the scenarios reflects the iMuSciCA STEAM pedagogy as each scenario starts from one of the STEAM ‘points of view’, i.e. Science/Mathematics, Engineering/Technology, Music, then connecting to the other STEAM fields, as further presented in [chapter 4](#).

### 3.1.2 An example of an ‘open’ scenario

The scenario with title ‘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

produced by his or her favorite instrument. Students first have to play the same tone on different instruments and experience that the sound produced is somehow different. This is done first by listening and then by measuring the frequency spectrum: the student will note that, when playing a tone on a musical instrument, not simply one frequency is produced but more. Students investigate then what happens by summing up different frequencies by using the ‘Tones Synthesizer’ and they come to the conclusion that it is the relative intensity of these frequencies which causes a different timbre. At this point they can proceed to the reproduction of the timbre of the chosen instrument.

	Analyze	S	<p>We try to reproduce a complex waveform by means of a <i>tone synthesizer</i>.</p> <p><b>Observation:</b> By adding up different frequencies we get a complex waveform. The timbre sounds differently depending on the strength of each of these frequencies.</p>	<p>Let us investigate how <i>simple waves sum up to form more complex waves</i> using the <i>Tone Synthesizer</i> (on the iMuSciCA workbench).</p> <p>Reproduce a tone A (la) of 220 Hz. This is called a ‘pure tone’ because it has no other frequency:</p>  <p>Let's add another tone. We will not add a random tone. Let's try the next natural tone first. What will be the frequency of the 2nd harmonic? <i>[ans. 440 Hz]</i> Make the sum of the 1st and 2nd harmonic.</p>	<p>You can find more information on <i>natural tones</i> in scenario 2.</p> <p>In the <b>Tone Synthesizer</b> you can change the frequencies by means of the slider at the right or by writing the desired value between parenthesis: <math>\sin(2\pi \cdot \dots)</math>. You can change the strength by writing a number between 0 and 1 in the first box (or by means of the slider at the left side).</p>
--	---------	---	---	---	---

**Figure 7:** Screenshot from scenario ‘Synthesize the timbre of your preferred instrument’.

In principle, this scenario can be considered as an independent one: in this case it can be considered as an example of scenario starting from an *engineering* point of view, as the students use some existing concepts and knowledge to ‘engineer’ something (i.e. to synthesize the timbre of a musical instrument) though without deepening the scientific and musical understanding of these ideas. However, teachers can decide to make a connection to other scenarios, starting from a scientific point of view, in order to deepen the scientific understanding of the used concepts, like e.g. tone and natural tones, or to deepen the artistic character of the timbre of an instrument. In this case they could implement some of the basic scenarios, which look at these concepts from the points of view of *physics, mathematics and music*.

### 3.1.3 Structure of scenarios dedicated to upper secondary

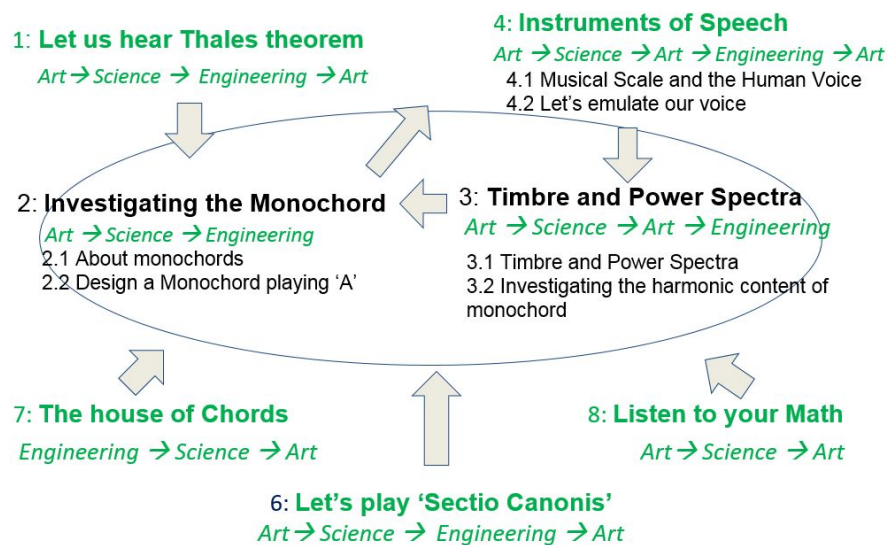
We present below in figure 8 the mutual connection between the scenarios dedicated to pupils of 14-17 years old (upper secondary level):

- 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 Maths*: 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*. Whatever you do, all the iMuSciCA scenarios use the workbench tools. In [appendix 1](#) you will find more details on which tools are used in the different scenarios.

## Pedagogical Coherence and **STEAM**-pedagogy of the iMuSciCA's Scenario's



**Figure 8:** Pedagogical coherence and STEAM fields for iMuSciCA's upper secondary scenarios.

## 3.2 Meta-info given for each scenario

The iMuSciCA scenarios are developed with and for teachers. Their function is that of supporting the work of teachers in using the workbench. Teachers are free to adapt scenarios according to their teaching goals. Of course teachers can also extract activities from the scenarios and prepare



worksheets for the students, which typically work in groups of 3-4. The structure of the scenarios is described in what follows.

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

**Figure 9:** iMuSciCA's synopsis of educational scenarios.

Figure 9 shows the synopsis of the iMuSciCA scenarios: this allows the teacher to create the overall 'floor plan' of teaching practices in terms of:

- **Inquiry Phase;**
- **STEAM field;**
- **Time**, i.e. duration of the activity;
- **Description** of the activity;
- **Activity:** specific teacher-student actions using the iMuSciCA workbench;
- **Remarks:** extra information for the teacher.

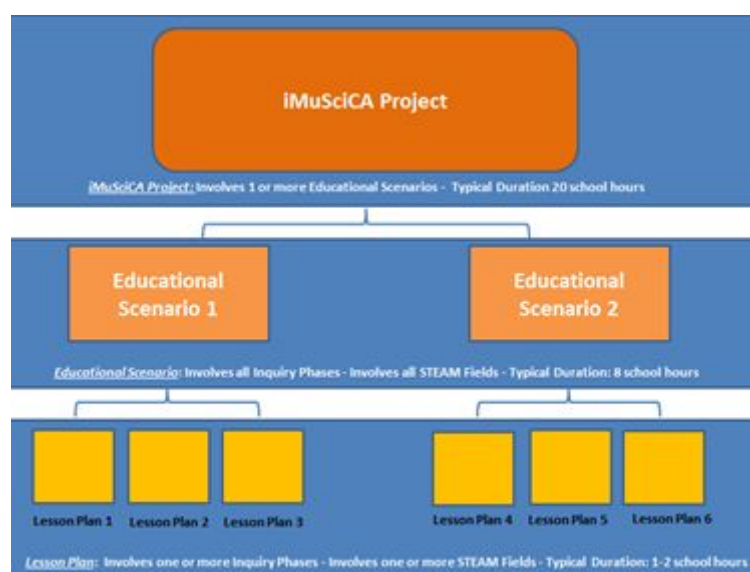
Its elements are self-contained interchangeable activities that can be easily combined and re-purposed.

To maximise flexibility of use, the scenarios developed by the iMuSciCA team, in co-creation with teachers, present a modular structure like the one shown in figure 10. This allows adaptations according to: National Curricula, structural differences between public schools, music schools and private schools, everyday practices in classrooms. The design of a scenario can be adapted to three possible settings: (i) long term Project Based Learning (PBL) that can be carried out e.g. in School Clubs and other programs of long duration foreseen in a specific country/school; (ii) medium term regular classroom interventions; or (iii) short term classroom interventions which go on par with the school curriculum. For more details concerning the possibilities in each country see [appendix 4](#).

According to this modular architecture, the iMuSciCA educational scenarios which are incorporating all IBSE phases and which are covering all STEAM fields usually have a duration of at least four hours and consist of smaller modules or Lesson Plans. Each Lesson Plan may incorporate one or more inquiry stages and has a typical duration of one or two teaching hours.

Educational Scenarios can be further combined, in order to produce a wider ranging and more comprehensive learning projects, which consist of at least one scenario and its duration can span from 20 hours to the whole school year.

This structure allows not only for flexibility with respect to the implementation setting, curriculum and time availability but also with regard to the design of the Educational Scenarios. As Scenarios consists of Lesson Plans involving one or more Inquiry Phases and STEAM fields, those Lesson Plans can be easily combined, varied and re-arranged in order to contribute to different Educational Scenarios.



**Figure 10:** Modular architecture of iMuSciCA's educational scenarios.

### 3.2.1 Ready to use Activity Books

For two basic scenarios (1. Sound and Tone and 2. Standing waves and resonant frequencies) 'ready to use' Activity Books were created in the form of an interactive digital learning book and online available. See [appendix 1](#) 'Overview of the scenarios' for a short description and the url's where you can find them.

Like all scenarios, these scenarios are the result of a long development work done by the iMuSciCA team in collaboration with teachers in Belgium and France. These scenarios were also tested in several schools in Belgium and in one school in France. They are thought to be deployed in the 7<sup>th</sup> and 8<sup>th</sup> grades but can in principle work, with some minor adaptations, in the 9<sup>th</sup> grade too.

## 3.3 How to implement the different STEAM points of view

Each scenario starts from a specific STEAM point of view and lets the user discover the connections to other STEAM fields. In fact it is the task of the teacher to make these connections explicit to the students and to choose on which parts of the scenarios to work in the class and how in depth to go with each step. It is especially recommended to make choice based on the field indicated in the dedicated column.

#### *Example:*

In a science lesson the teacher could decide to dedicate more time to the parts of the scenario signed with an 'S' (science) and just shortly introduce parts signed with 'A' (music). These parts could then be deepened during a music lesson.

Or: If you have the possibility to organize some 'block' of interdisciplinary lessons, please go ahead. But even then be careful that teachers from different backgrounds ('STEAM-team'!) can give scaffolding when needed.

In any case the piloting showed that It is important to keep into account expectations of students. Announce these lessons of interdisciplinary nature explicitly to the students. Indeed students are used to have only one subject and now you expect them to combine and connect them. Sometimes it was seen during certain pilotings of iMuSciCA that if students do expect a science or math lesson, they find it quite weird to be do actively something with music, especially when there is only a math



or science teacher present (and no music teacher). Of course iMuSciCA scenarios can be implemented in separate lesson hours, or in interdisciplinary hours (STEM-STEAM), as you like, depending on the school, the curriculum, the country. But In any case, bear in mind the expectations of learners towards normal class hours that you might want to change.

This issue is related to the fact that iMuSciCA is ideally taught by a *team* of teachers. So each teacher becomes part of a STEAM-team precisely because of his or her acquaintance with a certain STEAM-field. Like students, teachers contribute to the whole. Even in STEAM classes, subject matter experts are still needed so that students can professionally be scaffolded in science and math, engineering and technology or music. Being part of a STEAM team, this implies for students as well as for teachers to complement each other in order to discover the connections.

### **3.4 Pitfalls and suggestions while implementing iMuSciCA in your class**

Although the scenarios have been developed into detail, and students can typically work independently in groups of 3-4, the role of the teacher remains crucial. In this section a number of common pitfalls are described and suggestions of how to avoid these pitfalls are given.

#### **Teachers' interventions**

A first pitfall lies in the fact that pupils have a tendency to go through the scenario without waiting for timely interventions of the teacher. Without these interventions the students will lose track of the overview of the scenario and the research questions posed in the scenario.

To avoid this pitfall it is highly recommended to have a group discussion at the start of the scenario. At this time the main research questions and initial hypotheses of the students are discussed. This ensures that the students can keep an overview of the learning objectives.

For example in the scenario "Make your own string instrument" the following step-by-step plan can be used:

1. The teacher discusses the qualitative research question about the influence of length, tension and thickness on the tone of a string. In each group of students the hypotheses are formed and discussed.
2. Each group then performs the actual researches and activities explained in the scenario.
3. IBSE-phase (see below) are followed as reported in each scenario.

#### **Reflection moments**

A second pitfall is a result of lack of reflection moments. Teachers need to make time to discuss the results of all groups of students instead of focussing on one answer, perceived as correct, of a single group.

This pitfall can be avoided by making sufficient time available for the IBSE-phase 'communicate and reflect'.

Reflection moments shouldn't be limited to the end of a scenario but spread out throughout the scenario. For younger pupils it is better to divide the scenario in separate parts. After each part new insights are discussed. In this way the pupils will keep an overview of the structure of the scenario.

The following steps are repeated for each (part of the) research question:

1. Ask the class research questions and have the pupils form hypotheses.
2. Let the pupils perform the inquiry in group.
3. Reflect on the results with the whole class. Formulate the conclusions.

### **Virtual instruments are complementary to real ones**

Virtual tools can give you the right help next to real ones. While you never should forget dealing with real instruments too, and many times it is good to start with real ones, with the virtual ones students can experiment more freely, adapt more easy parameters that are far more difficult to change on a real instrument. For instance changing the thickness of strings is far more easily done on a virtual instrument.

So as a teacher, you can use both virtual and real-life instruments and experiments in a complementary way: a virtual environment like the iMuSciCA workbench is very useful to deepen the understanding of concepts which are more difficult to reproduce in real-life experiments. However it adds to them, it doesn't replace them.

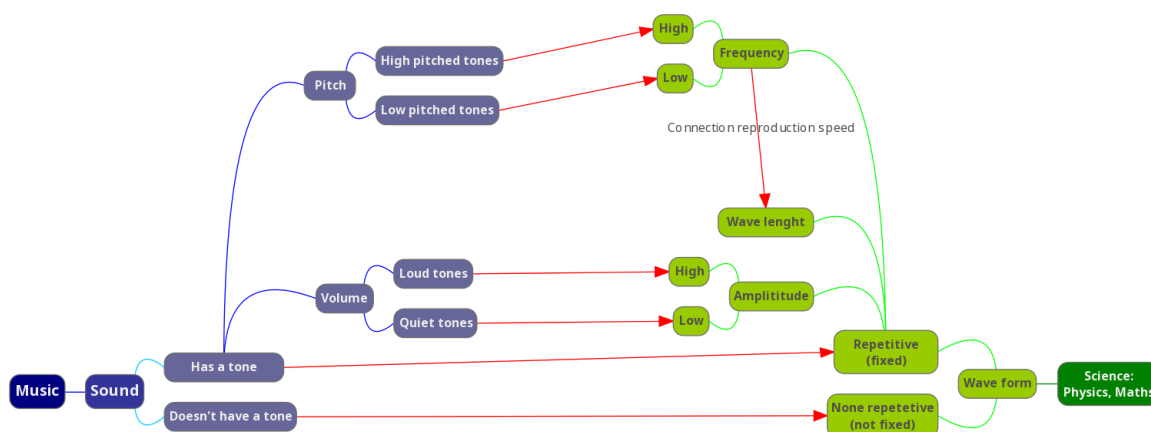
For example, in the scenario "Make your own string instrument", the teacher should use a real monochord at least in the introduction and once again in the reflection phase. Students need to experience at least once the influence of the length of the string on the tone on a real monochord. The influence of tension and thickness can than be simulated further on the virtual monochord.

In each developed scenario the teacher gets specific tips about rolling out the scenario in a classroom environment. These tips were included in the last column of the specific scenario. This is discussed in detail in the [section](#) about "the structure of scenarios".

## 4. Concepts in the iMuSciCA scenarios

When teachers and pupils get started with the iMuSciCA scenarios, it is important that they get a good overview of the concepts covered by each scenario and of the different links between them. To schematize the concepts and their relationships, for each scenario a concept map has been designed. A concept map is a visual representation of contents and key concepts. It also shows how these contents relate to each other, their relationships, in a knowledge network.

An example is shown below:



**Figure 11:** Concept map of scenario 1.2 What is tone?

A concept map gives a teacher an overview of the content pupils learn during the scenario. It enables teachers to discuss the content of specific course units in STEAM with their colleagues and to coordinate the various disciplines.

For pupils, a concept map can be a tool to communicate with other pupils about the scenario. In standard curricula pupils typically become familiar with the core concepts and contents of the scenario, but they often do not see all relationships between them, which are clear to the teacher as an expert in the field. The iMuSciCA concept maps allow to overcome this difficulty and to make the concepts and the relations between them explicit to the pupils.

Below, different possible approaches to the didactic use of concept maps are reported, which were tested during the iMuSciCA piloting phases.

- Show the concept map to pupils and explain it into detail: define the core concepts and their relationships.
- Develop the concept map step by step throughout the scenario together with your students: make parts of the map visible step by step and show where the complete scenario will lead to. The entire concept map in all its complexity is then only fully shown at the end.
- Show the whole concept map from the start of the scenario to zoom then in on parts of it for each lesson plan.
- Have students create themselves a concept map. The teacher can choose the appropriate timing for this 'design yourself'.

In [appendix 2](#) you find the concept maps designed for each scenario.

## 5. An iMuSciCA Use Case Scenario: Synthesize the timbre of your preferred musical instrument

Here we illustrate the overall value of iMuSciCA's pedagogy by means of a concrete example scenario. The example illustrative scenario is: [\*Synthesize the timbre of your preferred musical instrument\*](#). This scenario mainly works with iMuSciCA's tone synthesizer on the workbench.

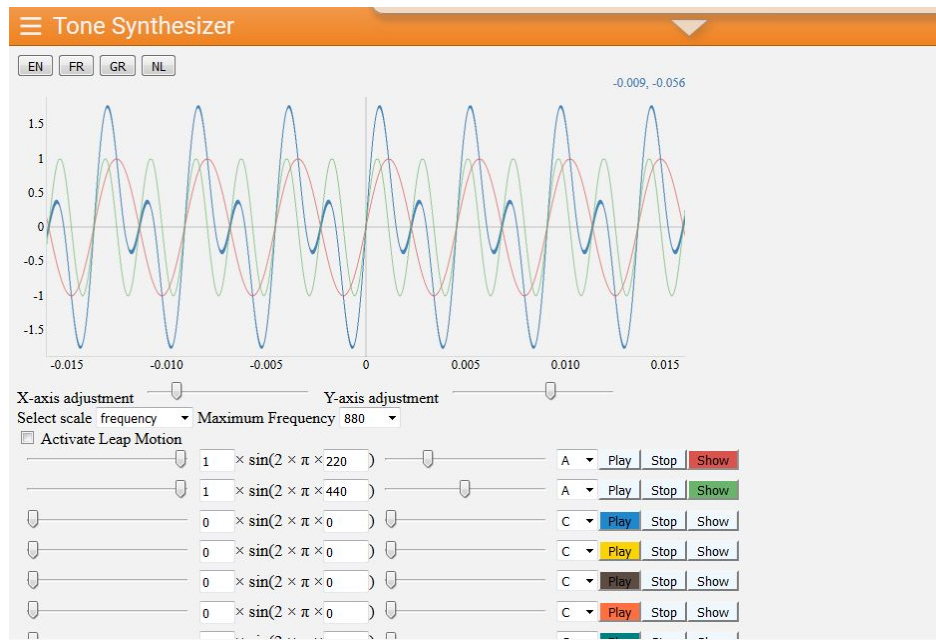


Figure 12: Tone Synthesizer on the iMuSciCA workbench.

### 5.1 A motivating scenario: Synthesize the timbre of your preferred musical instrument

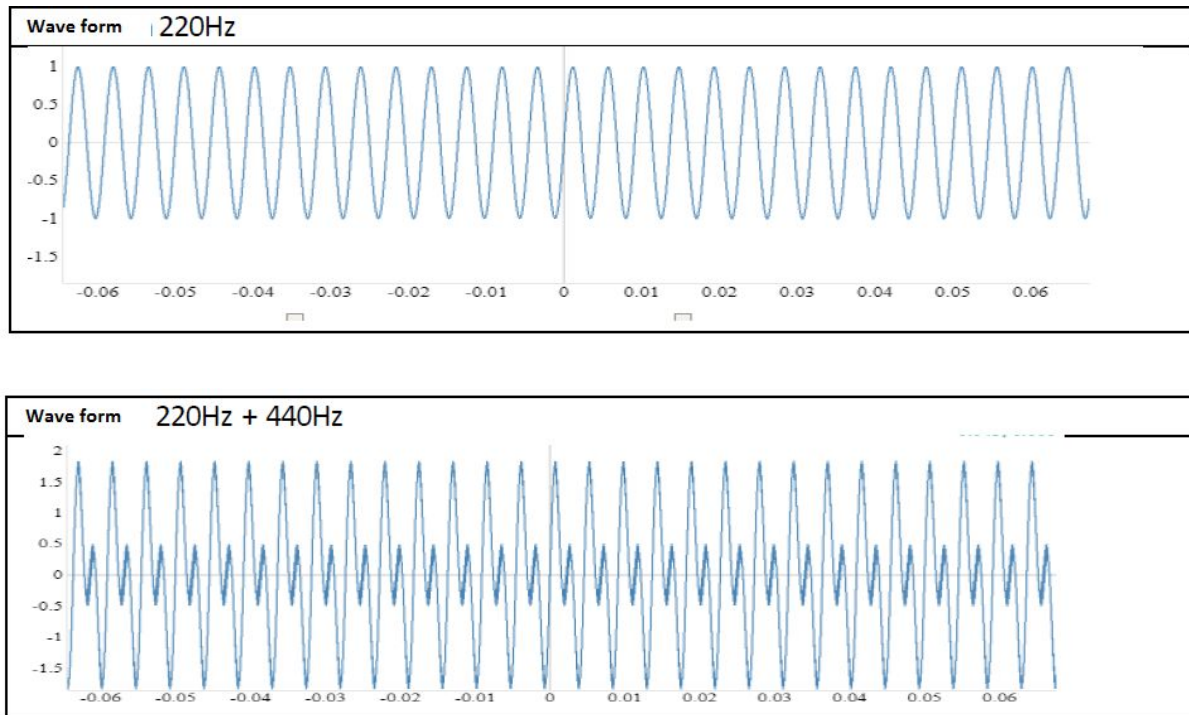
The goal of *Synthesize the timbre of your preferred musical instrument* is to synthesize a sound similar to one produced by your favourite instrument. For instance: if the guitar is your favourite instrument, you are going to reproduce the timbre (tone colour) of a guitar by means of the iMuSciCA tone synthesizer on the workbench. So the start of this scenario is a **question from the engineering field**: to reproduce, to synthesize, the sound of a musical instrument.



So you are trying to make a simple synthesizer!

To create your desired timbre, just like a real engineer:

- you are going to use a mathematical model for tone colour: the tone colour is the result of a superposition of upper tones with different 'weight' factors.
- you can measure the relative weight of the upper tones of your preferred instrument by measuring the spectrum.
- you can add the different component waves on iMuSciCA's tone synthesizer. While altering the relative strength of the different single waves, you come closer to the desired resulting wave form and thus closer to the timbre of a your instrument.



**Figure 13:** Example of waveforms produced with a tone synthesizer: above a simple wave of 220 HZ, below the sum of a wave of 220 Hz and one of 440 Hz.

So what you do in this scenario, like in many other iMuSciCA's scenarios:

- You are starting from some questions taken from one field (in this example the engineering field).
- You connect these questions with investigations in some other field (like in iMuSciCA's tone synthesizer: students use the mathematical model of Fourier Synthesis on a conceptual way in order to understand the timbre in music).
- You connect these insights from one field to another (in this case: you connect the science and the engineering thinking to the experience of listening to the timbre of an instrument).

So we let the students play the 'whole play' (Perkins, 2010). Many times in learning it occurs indeed that what is learned is only a part of something bigger. For instance in class it can occur that to students is explained that periodic functions (or some other concept for that matter) are the basics of music and that these learned concepts are further applied in other fields as well. For instance when an engineer designs a synthesizer he or she will use insights from music and science. But in iMuSciCA students will not just hear about this, students will connect for instance scientific concepts themselves to music and engineering (and the other way around). One of the scenarios lets the students design, like a real engineer, the timbre of a chosen instrument. So in iMuSciCA students can

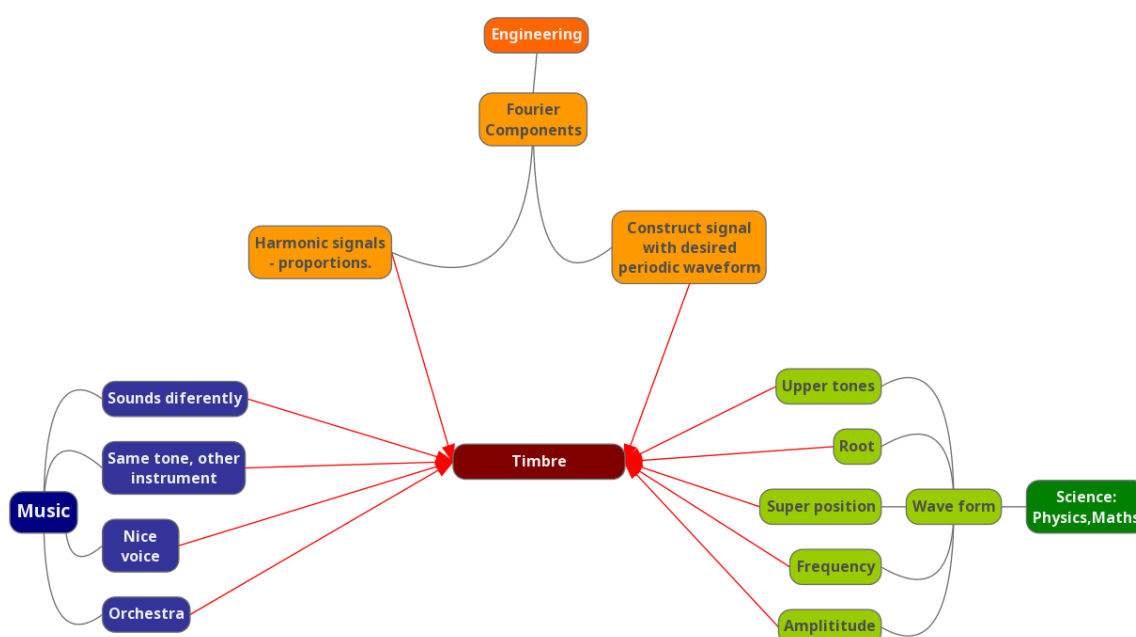
play really the ‘whole’ game. iMuSciCA avoids getting stuck in a ‘learning about’ but stimulates student’s **learning by playing the whole game** (included the games situated in other fields).

Deeper and intrinsic motivation comes from within (Ryan & Deci, 2000): the question is to trigger the desire to understand main concepts or to perform an integrated task like this one (synthesize the timbre of an instrument). iMuSciCA *challenges students to get the **whole picture of different fields and synthesize it in a solution***. Hence, the interdisciplinary nature of iMuSciCA makes the learning more relevant to learners which increases the possibility to trigger intrinsic motivation (21st century skills).

## 5.2 Concepts & skills across fields: discovering a more complete picture

We will illustrate now how a scenario like the one about timbre is built around some core concepts and skills from different fields: music, science, maths and engineering. Indeed skills and concepts are not the same in all these field, although related. iMuSciCA wants to also show here the whole picture (or at least a more complete one) .

With the example ‘Synthesize the timbre of your preferred musical instrument’ we illustrate here how, as is done in every iMuSciCA scenario, different concepts from different fields contribute to a more complete understanding of a certain phenomenon (in this case: timbre).



**Figure 14:** Concept map of the scenario ‘Synthesize the timbre of your preferred musical instrument’.

Of course while this scenario is about timbre, you will find the phenomenon of timbre central in the concept map. On the side you’ll discover how ‘timbre’ is connected to the fields of Music, Science and Engineering.

**Music:** can you experience that in music timbre has to do with orchestration, recognizing a voice or the tone colour of an instrument?

In **Science** (Maths and Physics) one tries to understand sound by functions that are periodic in time. Periodic waves of which the frequencies are entire multiples seem to play an important role in music. Timbre is then understood as a superposition of harmonic periodic waves each with a certain amplitude in order to get a resulting wave.

In **engineering** you want *to construct* a signal with a desired periodic waveform containing the harmonic content you want it to have. So you use the scientific model to create the desired timbre.

Therefore, the difference between science (it is enough if we can understand and explain the phenomenon with a predictive mathematical model!), engineering (you want to construct something using scientific models) and music (which is about making and experiencing the timbre of sounds) can be experienced by the students. This way students in iMuSciCA learn to see a more complete ‘picture’, seen from different perspectives, from different fields.

The concepts used in each scenario are schematically summarized in [appendix 2](#). It is also important that teachers make these concepts explicit to the learner too.

### 5.3 Possible paths for ‘*Synthesize the timbre of your preferred musical instrument*’

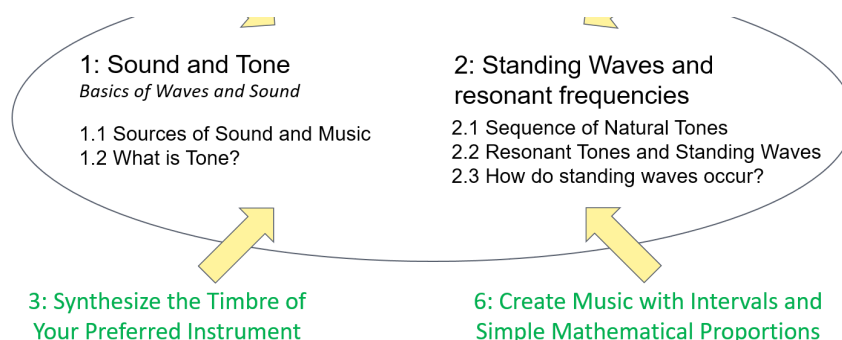
The educational objectives of this scenario are:

1. The students can show and explain how it comes that the same tone sounds different on different instruments.
2. The students can measure the frequencies and relative strength of the partials that determine the timbre of an instrument.
3. The students can, to some approximation, synthesize the timbre of a particular instrument by adding partials with proper relative strengths (using iMuSciCA’s tone synthesizer).
4. Extra: The students can show and explain how a resonance box influences the timbre of sound.

Like every iMuSciCA scenario you can give more or less guiding or you can choose for a more open inquiry depending on what your students can take. This scenario *Synthesize the timbre of your preferred musical instrument* could for instance be the challenging start of their journey in the world of music, science and engineering.

However, more challenging approaches ask for appropriate scaffolding of students especially for those with weaker backgrounds, as pointed out in [section 1.1.3](#) (Kirschner et al., 2006).

The iMuSciCA scenarios give exactly these needed scaffolding. A scenario refers to prior knowledge your students might need, which can be included in more ‘basic scenarios’: e.g. on tones and frequencies (scenario 1), on waves and how resonant tones occur (scenario 2).



**Figure 15:** Link between scenario ‘Synthesize the timbre of your preferred musical instrument’ and the more ‘basic scenarios’: ‘Sound and tone’ and ‘Standing waves and resonant frequencies’.

When students are busy with the challenging *Synthesize the timbre of your preferred musical instrument* you might as well refer your students to these scenarios when needed.

In the concept maps of the different scenarios you’ll see where your students can find more background information on certain concepts (see [appendix 2](#) for the concept maps of each iMuSciCA Scenario).


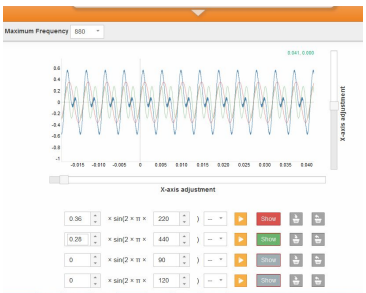
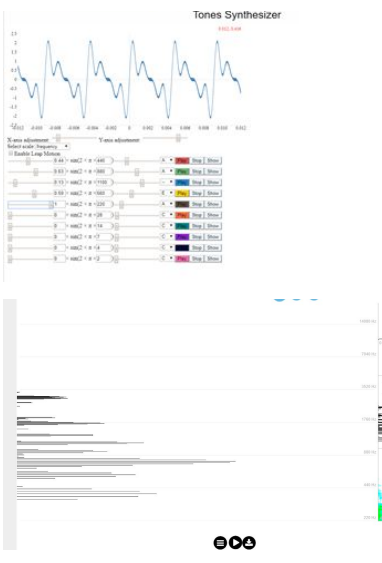
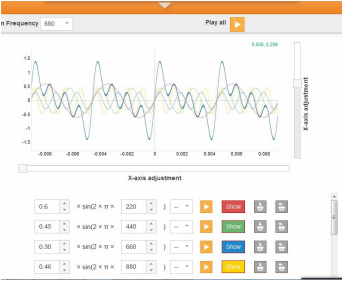
Moreover, in the scenario’s last column, like in every iMuSciCA scenario, you will find more suggestions and also background your students might need when performing the task (see [section 3](#) for the detailed structure of present and other scenarios).

Whatever approach you choose, this scenario *Synthesize the timbre of your preferred musical instrument*, like every other iMuSciCA scenario, gives your students a journey through different fields. It gives the chances to connect different fields hitherto mostly left unconnected: music, science, mathematics and engineering.

The scenario *Synthesize the timbre of your preferred musical instrument* starts with an engineering question (to *design* a timbre) in connection with the musical world. It connects to a mathematical model that is used to engineer the desired timbre. It ends in the musical world by listening to the designed timbre and comparing it to the real one. We give below an overview of this interdisciplinary journey.

Music	Science/Maths	Engineering/ Technology
		We start with an engineering question: the aim is to reproduce or synthesize, the sound of a musical instrument.
Listen to the same tone on your preferred instrument compared to the same tone produced on another instrument.		



	<p>Why does the same tone sound differently on different instruments?</p> <p>Does it has to do with different (complex) waveforms?</p> 	
	<p>Could it be that the more complex wave is the result of the sum (superposition) of a few simple waves?</p> 	
	<p>Measure the spectrum of a tone of your preferred instrument: frequencies and relative strengths of the partials.</p> 	<p>Use the superposition of partials as a mathematical model to synthesize the desired timbre.</p> 
Listen to the designed timbre and compare it to the desired one.		

In fact it is possible to perform the scenario in a very challenging and open way by just providing the students with the questions in the table above. Students can then ‘play’ with the iMuSciCA tone synthesizer with some scaffolding when needed.

## Conclusion

The iMuSciCA workbench together with the iMuSciCA scenarios and lesson plans comprise powerful tools to bring the real STEAM world into the classroom. The aim is to inspire you, teachers, in this task and to give you support. Let start this wonderful trip through the STEAM world, let’s encounter new concepts in one of the STEAM fields and connect them to concepts of other STEAM fields! Don’t forget to make these steps explicit to students, so that they understand how it works in the real STEAM world, where people of different backgrounds work together to investigate, understand or create something.

As a teacher you can always keep this pedagogical guide next to you whenever doing an iMuSciCA activity in the class. Remember that the aim of the developed scenarios is not to tell you how to use the workbench, but to inspire you. So feel free to adapt the existing scenarios and to develop new ones based on your experience, on your students and on your school and national curriculum. Also don’t forget to collaborate with your colleagues, as STEAM is really a **team** work, both in the STEAM world outside the school as well as inside school.

# References

- [Bartos & Lederman, 2014] Bartos, S. A., & Lederman, N. G. (2014). Teachers' knowledge structures for nature of science and scientific inquiry: Conceptions and classroom practice. *Journal of Research in Science Teaching*, 51(9), 1150-1184.
- [Csikszentmihalyi, 2008] Csikszentmihalyi M. (2008). Implications of a systems perspective for the study of creativity. In Steinberg R.J. (Ed.), *Handbook of Creativity* (pp. 313–335). New York, NY: Cambridge University Press.
- [Czerniak & Johnson, 2007] Czerniak, C. M., & Johnson, C. C. (2007). Interdisciplinary science teaching. *Handbook of research on science education*, 537-559.
- [Dweck, 2000] Dweck C. (2000). *Self-theories: Their role in motivation, personality, and development* (Essays in social psychology). Philadelphia, PA: Psychology Press.
- [Fogarty, Perkins & Barell, 1992] Fogarty R., Perkins D., & Barell J. (1992). *How to teach for transfer*. Palatine, IL: Skylight Publishing.
- [Honey et al., 2014] Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press
- [Honey & Kanter, 2013] Honey, M., & Kanter, D. (2013). *Design, make, play: Growing the next generation of STEM innovators*. New-York: Routledge.
- [Kim & Park, 2012a] Kim, Y., & Park, N. (2012). Development and application of STEAM teaching model based on the Rube Goldberg's invention. In *Computer science and its applications* (pp. 693–698). The Netherlands: Springer.
- [Kim & Park, 2012b] Kim, Y., & Park, N. (2012). The effect of STEAM education on elementary school student's creativity improvement. In *Computer applications for security, control and system engineering* (pp. 115–121). Berlin Heidelberg: Springer.
- [Kirschner, 2001] Kirschner, P. A. (2001). Using integrated electronic environments for collaborative teaching/learning. *Research Dialogue in Learning and Instruction*, 2(1), 1–10
- [Kirschner et al., 2006] Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational psychologist*, 41(2), 75-86.
- [Lederman & Niess, 1997] Lederman, N. G., & Niess, M. L. (1997). Editorial. *School science and Mathematics*, 97(7), 341-344.
- [Jensen & Nickelsen, 2008] Jensen, E., & Nickelsen, L. (2008) *Deeper learning: 7 powerful strategies for in-depth and longer-lasting learning*. Corwin Press.
- [Martinez & Stager, 2013] Martinez, S. L., & Stager, G. (2013). *Invent to learn: A guide to why making should be in every class*. Torrance, CA: Constructing Modern Knowledge Press.
- [Matthews, 1994] Matthews, M. R. (1994). *Science teaching: The role of history and philosophy of science*. Psychology Press.
- [Perkins & Grotzer, 2005] Perkins, D. N., & Grotzer, T. A. (2005). Dimensions of causal understanding: The role of complex causal models in students' understanding of science.
- [Perkins, 2010] Perkins, D. N. (2010). *Making learning whole: How seven principles of teaching can transform education*. John Wiley & Sons.
- [Quigley et al., 2017] Quigley, C. F., Herro, D., & Jamil, F. M. (2017). Developing a Conceptual Model of STEAM Teaching Practices. *School Science and Mathematics*, 117(1-2), 1-12.
- [Rankin, 2011] Rankin, L. (2011). Pathways to inquiry. *Science and Children*, 48(6), 8-9.
- [Robinson, 2001] Robinson K. (2001). Mind the gap: The creative conundrum. *Critical Quarterly*, 43 (1).
- [Ryan & Deci, 2000] Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American psychologist*, 55(1), 68.

- [Saavedra & Opfer, 2012] Saavedra, A. R., & Opfer, V. D. (2012). Learning 21st-century skills requires 21st-century teaching. *Phi Delta Kappan*, 94(2), 8-13.
- [Salomon G. & Perkins D., 1989] Salomon G. & Perkins D. (1989). Rocky roads to transfer: Rethinking mechanism of a neglected phenomenon. *Educational Psychologist*, 24 (2), 113.
- [Schwartz & Fischer, 2006] Schwartz M. & Fischer K. (2006). Useful metaphors for tackling problems in teaching and learning. *About Campus*, 11 (1), 2–9.
- [Sternberg, 2006] Sternberg R. J. (2006). The nature of creativity. *Creativity Research Journal*, 18 (1), 87–98.
- [Tamassia & Frans, 2014] Tamassia, L., & Frans, R. (2014) Does integrated science education improve scientific literacy? *Journal of the European Teacher Education Network*, 9, 131-141.
- [Tiberghien, A., 2000] Tiberghien, A. (2000). Designing teaching situations in the secondary school. In R. Millar, J. Leach & J. Osborne (Eds.), *Improving science education: The contribution of research* (pp. 27-47). Buckingham, UK: Open University Press.
- [Tsuprost et al., 2009] Tsupros, N., R. Kohler, and J. Hallinen.(2009). STEM education in Southwestern Pennsylvania: Report of a project to identify the missing components. Center for stem education and Leonard Gelfand center, Carnegie Mellon University
- [Wagner, 2008] Wagner T. (2008). *The global achievement gap: Why even our best schools don't teach the new survival skills our children need — and what we can do about it*. New York, NY: Basic Books
- [Yackman, 2008] Yackman, G. (2008). “STEAM education: An overview of creating a model of integrative education,” presented at the Pupils' Attitudes Toward Technology (PATT-19) Conference: Research on Technology, Innovation, Design & Engineering Teaching, Salt Lake City, Utah.

# Appendix 1 - Overview of the scenarios

Below we present an overview of the iMuSciCA scenarios developed by the project pedagogical team. The scenarios are presented in two groups:

- focussing on lower secondary pupils, i.e. 12-15 years old (available in English, Dutch and French)
- focussing on upper secondary pupils, i.e. 14-17 years old (available in English, Greek and planned in Dutch).

For each scenario we report the title, a short description and a list of the workbench activity environments and tools used in that scenario. As already underlined in [chapter 3](#), the aim of these scenarios is to offer inspiration, support and background information to teachers, while giving them and their students 'choice' among different possible 'paths'. Furthermore we remind that you are free to adapt the scenarios to your class situation or even to develop new scenarios. You can also get an idea how to use the various activity environments and tools available on the workbench.

## Scenarios focussing on lower secondary pupils, i.e. 12-15 years old

Title of Scenario	Short description and url	Used activity environments and tools on the iMuSciCA workbench
Scenario 1: Sound and tone	<p>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 consists out of two lesson plans, both in 'ready to use' Activity Book format:</p> <p><a href="#">1.1 Sources of Sound and Music</a>  <a href="#">1.2 What is Tone?</a></p> <p>You can find the teachers' scenarios format here:  <a href="#">1.1 scenario: Sources of Sound and Music</a>  <a href="#">1.2 scenario: What is Tone?</a></p>	<p>Visualizations tools to analyse the different waveforms of external sounds.</p> <p>DrAwME: The musical whiteboard: create tone and sound.</p> <p>Music Tools: to measure the actual Hz, the metronome for musical exercises.</p> <p>Performance sampler: which are sounds vs tones; build a soundscape.</p>
Scenario 2: Standing waves and resonant frequencies	<p>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</p>	<p>Visualizations tools: to measure whistle frequencies.</p> <p>DrAwME: The musical whiteboard: natural tones.</p>

	<p>don't change anything. This scenario consists of three lesson plans, in 'ready to use' Activity Book format:</p> <p><a href="#">2.1: The sequence of natural tones</a></p> <p><a href="#">2.2: Natural Tones and Standing Waves</a></p> <p><a href="#">2.3 How do standing waves occur?</a></p> <p>You can find the teachers' scenarios format here:</p> <p><a href="#">2.1: scenario: The sequence of natural tones</a></p> <p><a href="#">2.2: scenario: Natural Tones and Standing Waves</a></p> <p><a href="#">2.3 scenario: How do standing waves occur?</a></p>	
Scenario 3: Synthesize the timbre of your preferred instrument	<p>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. It was developed according to the new strategy in co-creation with iMuSciCA teachers in Belgium by UCLL.</p> <p>You can find the teachers' scenarios format here:</p> <p><a href="#">Scenario 3: Synthesize the timbre of your preferred instrument</a></p>	<p>Tones Synthesizer: this scenario is centred around this tool. How simple waves sum up to form more complex waves.</p> <p>Visualizations tools: to measure frequencies.</p> <p>Music Tools: frequency meters to discover overtones, reproduce them on the synthesizer.</p>
Scenario 4: Create a piece of music using geometric symmetries	<p>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!</p> <p>It uses various iMuSciCA tools on the workbench like the 'Performance Sample Sequencer', the 'Drawing Canvas for Music Creation', the 'Geometry and Algebra tools'.</p> <p>You can find the teachers' scenarios <a href="#">Create a piece of music using geometric symmetries</a> consisting out of following lessons:</p> <p>4.1: Discovering symmetry in music and mathematics</p> <p>4.2: Transformations in music and mathematics</p> <p>4.3: Combinations of transformations in music and mathematics</p> <p>Print the cards that go with this scenario: this will help your students to solve the different</p>	<p>Performance sampler: create a composition.</p> <p>Geometry and algebra: transformations, rotations and reflections of figures in relation with music.</p> <p>More help on <b>how to perform geometrical symmetry operations</b> (like translations, reflections, rotations...) <b>on the iMuSciCA Geometry &amp; Algebra tools</b> can be found at this <a href="#">help document</a>.</p> <p>DrAwME: The musical whiteboard: reproduction of imuscica melody, reflection and transformation.</p>

	<p>assignments in combination with iMuSciCA's workbench tools DrAwMe and iMuSciCA's Geometry and Algebra tools. You find a printable file:</p> <ul style="list-style-type: none"> <li>- with the <a href="#">cards</a></li> <li>- with one transparent <a href="#">figure</a></li> </ul>	
Scenario 5: Make your own string instrument	<p>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 the students can play with a virtual instrument on iMuSciCA's 3D instrument interaction.</p> <p>You can find the teachers' scenarios format here: <a href="#">Scenario 5: Make your own string instrument</a></p>	<p>3D Virtual Instrument Design: work with the monochord to investigate the influence of radius, length, tension on the frequency.</p> <p>Visualizations tools: discover the difference in frequency whilst playing with above tools.</p> <p>3D Instrument Interaction: when the virtual instrument is created, the student can play on it connecting a motion sensor and interacting with iMuSciCA's 3D instrument interaction.</p>
<a href="#">Scenario 0: The workbench</a>	<p>This scenario gives an overview on possible ways to implement the iMuSciCA tools on the workbench. The aim is to inspire teachers, to give them ideas on the potential use of the tools in the class practice.</p>	<p>All workbench activity environments and tools.</p>

#### Scenarios focussing on upper secondary pupils, i.e. 14-17 years old

Title of Scenario	Short description and url	Used activity environments and tools on the iMuSciCA workbench
Scenario 1: Let's hear Thales' theorem	<p>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</p>	<p>DrAwME: The musical whiteboard.</p> <p>Geometry and algebra.</p>

	<p>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.</p> <p>You can find the teachers' format of this scenario here:  <a href="#">Scenario 1: Let's hear Thales' theorem</a></p>	<p>3D Virtual Instrument Design.</p> <p>Sound recorder.</p> <p>Performance sampler.</p> <p>3D Instrument Interaction.</p>
Scenario 2: Investigating the monochord	<p>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 simulated data produced by the performance of the virtual instrument. This scenario consists out of two lesson plans:</p> <p>You can find the teachers' format of this scenario here:  <a href="#">2.1 About monochords</a>  <a href="#">2.2 Design a Monochord playing 'A'</a></p>	<p>3D Virtual Instrument Design.</p> <p>Visualizations tools.</p> <p>Music tools: Tuner</p> <p>3D Instrument Interaction.</p>
Scenario 3: Timbre and power spectra	<p>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 harmonic content of sound. Students will experiment with different virtual musical instruments and investigate why</p>	<p>Tones Synthesizer.</p> <p>DrAwME: The musical whiteboard.</p> <p>3D Virtual Instrument Design.</p>



	<p>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.</p> <p>This scenario consists out of two lesson plans:  <a href="#">3.1 Timbre and Power Spectra</a>  <a href="#">3.2 Investigating the harmonic content of monochord</a></p>	<p>3D Instrument Interaction.</p> <p>Visualizations tools.</p>
Scenario 4: Instruments of speech (Volume 1)	<p>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.</p> <p>You can find the teachers' format of this scenario here:  <a href="#">Scenario 4: Instruments of speech (Volume 1)</a></p>	<p>3D Virtual Instrument Design.</p> <p>Visualizations tools: 2D analyzer</p> <p>Music tools: Tuner</p> <p>3D Instrument Interaction.</p> <p>Tones Synthesizer.</p> <p>DrAwME: The musical whiteboard.</p>
Scenario 5: The house of chords	<p>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 consonances or dissonances as a result of building chord sequences and finally they record it using the virtual instruments produced to play it.</p> <p>You can find the teachers' format of this scenario here:  <a href="#">Scenario 5: The house of chords</a></p>	<p>3D Virtual Instrument Design</p> <p>Geometry &amp; Algebra</p> <p>Tone Synthesizer</p> <p>3D Instrument Interaction</p> <p>Snail</p> <p>Tone Synthesizer</p>

<p>Scenario 6: Let's play 'Sectio Canonis'</p>	<p>Within the 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.</p> <p>You can find the teachers' format of this scenario here:  <a href="#">Scenario 6: Let's play 'Sectio Canonis'</a></p>	<p>3D Virtual Instrument Design</p> <p>Geometry &amp; Algebra</p> <p>Tone Synthesizer</p> <p>3D Instrument Interaction</p>
<p>Scenario 7: Instruments of speech (Volume 2)</p>	<p>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.</p> <p>This scenario consists out of two lesson plans:  <a href="#">4.1 Musical Scale and the Human Voice</a>  <a href="#">4.2 Let's emulate our voice</a></p> <p>The scenario uses moreover the lesson plans of scenario <i>Timbre and Power Spectra</i> and of scenario <i>Investigating the Monochord</i></p>	<p>3D Virtual Instrument Design.</p> <p>Visualizations tools: 2D analyzer</p> <p>Music tools: Tuner</p> <p>3D Instrument Interaction.</p> <p>Tones Synthesizer.</p> <p>DrAwME: The musical whiteboard.</p>
<p>Scenario 8: Listen to your math</p>	<p>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. Then, they identify the notes of the sound produced and reproduce them with virtual musical instruments of their own design.</p>	<p>Drawme</p> <p>Sonification</p> <p>Geometry and Algebra</p> <p>Music tools: Recorder</p> <p>Math editor</p>

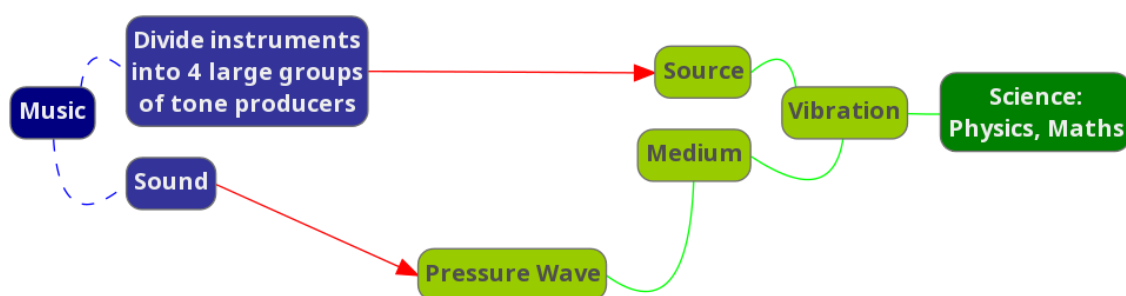
	<p>You can find the teachers' format of this scenario here:</p> <p><a href="#">Scenario 8: Listen to your math</a></p>	
--	--	--

## Appendix 2 - Concept maps

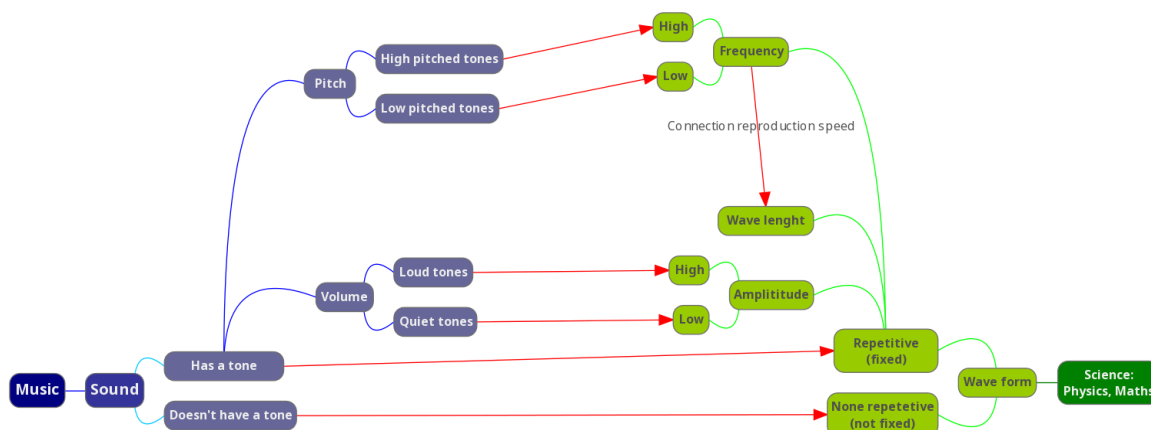
The concept maps developed for each scenario are listed below. Each concept map shows the discipline from which the concepts originate and how they relate to core concepts of other STEAM disciplines. Concepts from physics are shown in green, concepts from mathematics are shown in yellow and concepts from music are shown in blue. Elements that are listed in gray are not discussed in the scenario itself. As these elements are related to subjects taught in later academic years, they are included in the concept map.

### Concept maps scenarios for lower secondary

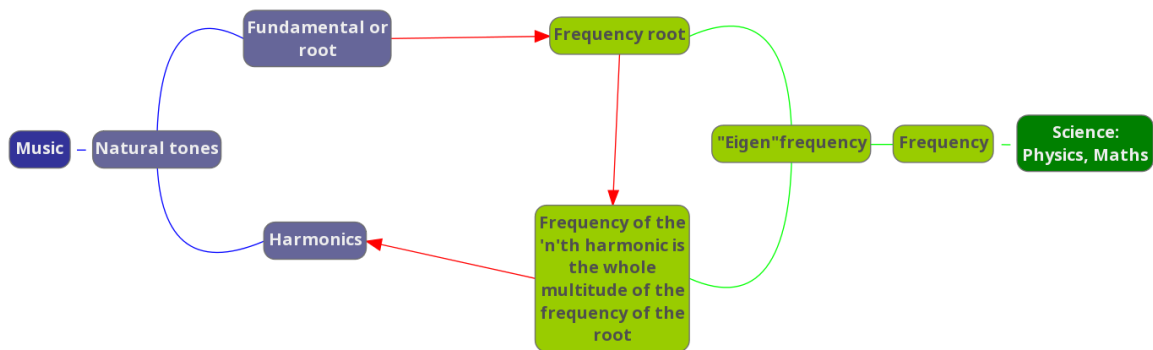
#### Concept map scenario 1.1: Sources of sound



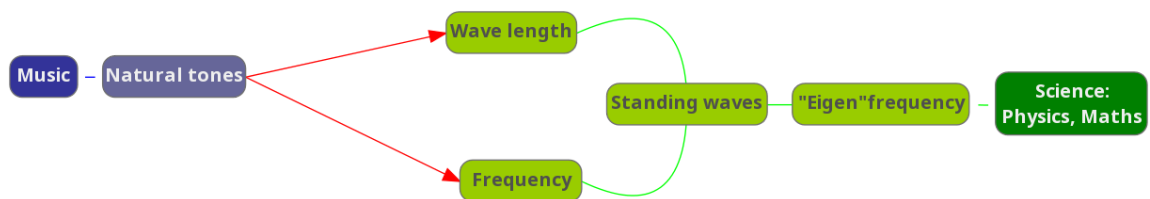
#### Concept map scenario 1.2: What is tone?



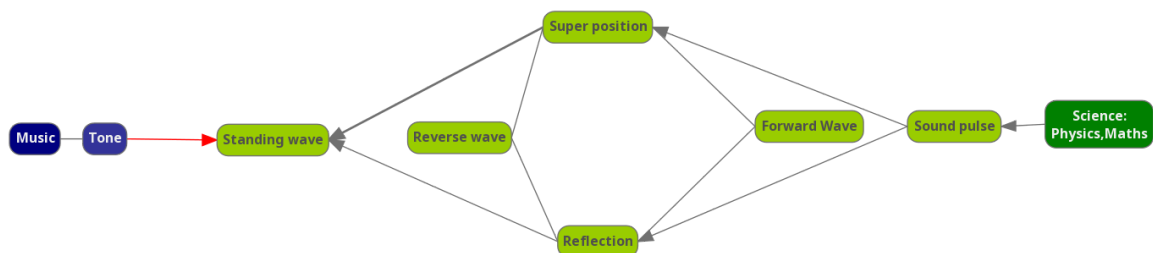
### Concept map scenario 2.1: The sequence of natural tones



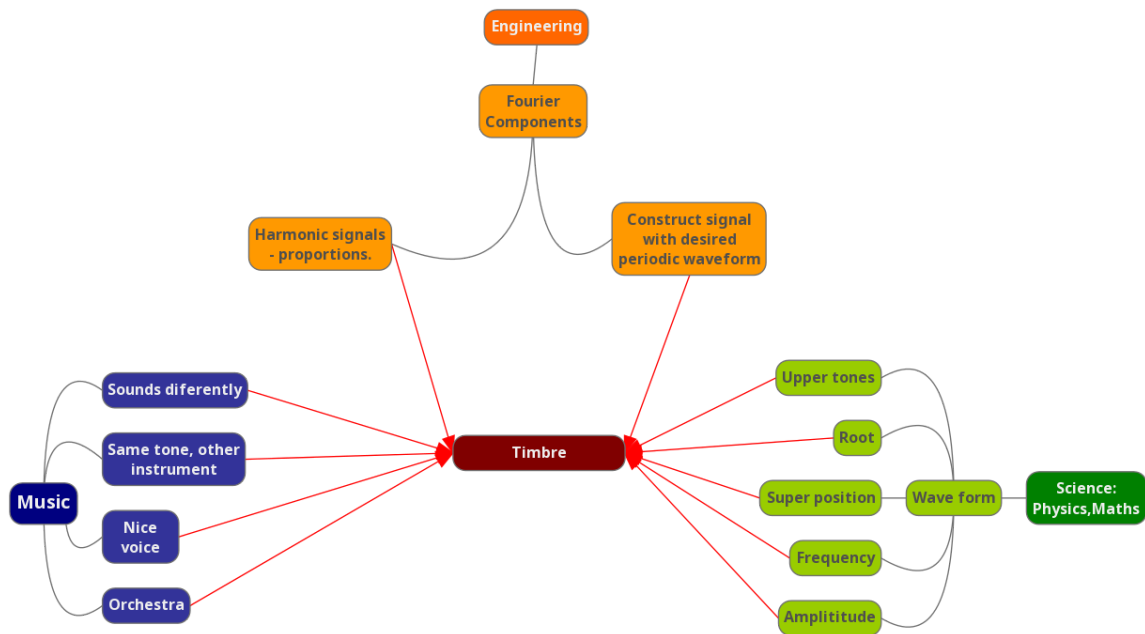
### Concept map scenario 2.2: Natural tones and standing waves



### Concept map scenario 2.3: How do standing waves occur?

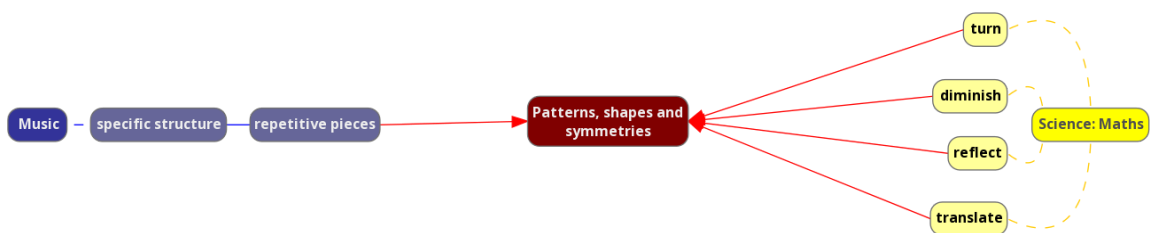


### Concept map scenario 3.1: Synthesize the timbre of your preferred instrument

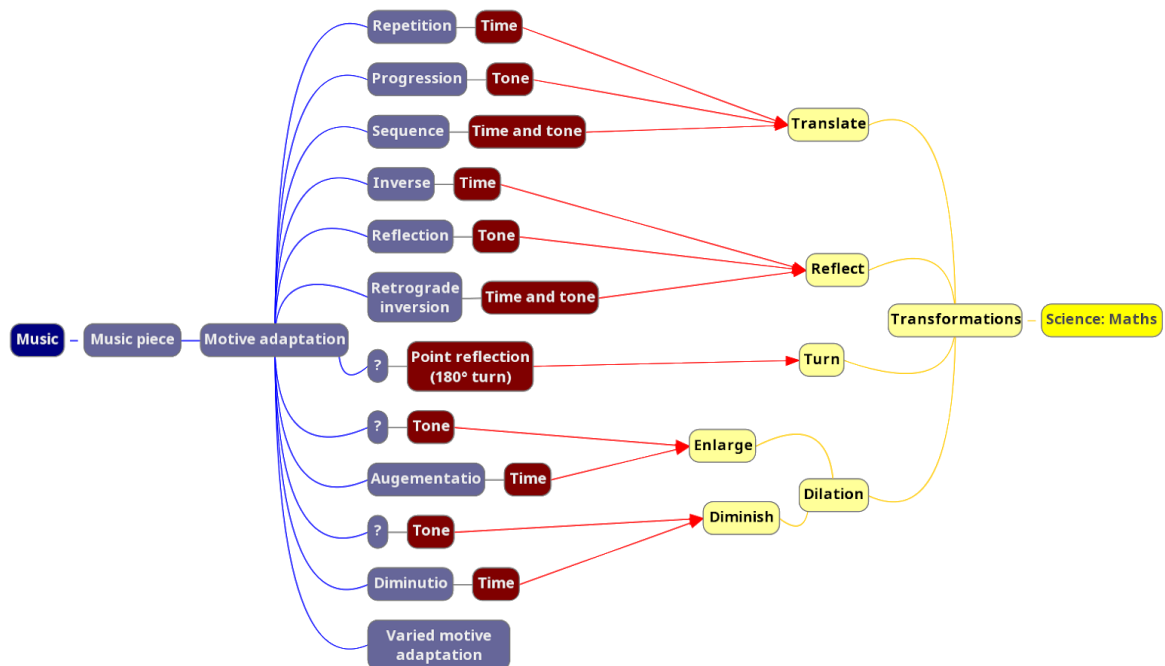


### Concept map scenario 4: Build a musical piece using geometrical symmetry

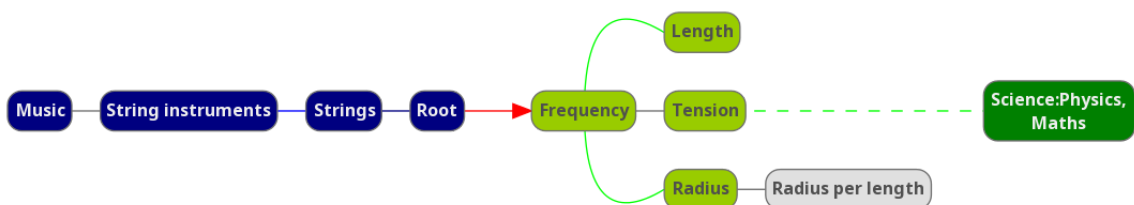
#### 4.1 Patterns in music and mathematics



## 4.2 Transformations in music and mathematics



### Concept map scenario 5.0: Make your own string instrument



## Appendix 3 - iMuSciCA's IBSE pedagogy

You will find here more details on how iMuSciCA's innovative IBSE pedagogy works across the different STEAM-fields as contrasted to IBSE education in single subject classes.

In iMuSciCA, attention is given both to the identity of every STEAM discipline, its concepts and practices, *as well as to the connections between the fields*. Therefore, **the traditional IBSE phases are broadened so to make room for activities usually not incorporated in science inquiry**. The phases have, although connected, slightly different meanings in the different STEAM fields. Therefore iMuSciCA introduces the following STEAM Inquiry phases that imply inquiry in and between the fields and foster diverse *collaborative activities where connections* between the STEAM-fields become real.

Note that the different inquiry phases and STEAM fields can be visited in a pathway over different lessons of a certain scenario. It can be imagined as follows:

	STEAM field			
		Music	Science /Math	Engineering /Technology
STEAM Inquiry Phase	Engage	Lesson 1		
	Imagine		Lesson 1	
	Create <i>Investigate/Design</i>	Lesson 4	Lesson 2	Lesson 2
	Analyse		Lesson 3	
	Communicate & Reflect	Lesson 4	Lesson 3	

**Table 1.** In a scenario, spread over some lessons, different inquiry phases and STEAM fields can be visited.



Or it is also possible that within one lesson different phases and fields are visited.

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

**Table 2.** Different inquiry phases and STEAM fields can also occur in one lesson.

Now we will explain how iMuSciCA's innovative IBSE pedagogy works across the different STEAM-fields as contrasted to IBSE education in single subject classes:

1. Engage
2. Imagine
3. Create
4. Analyse
5. Communicate and reflect

### 1. Engage (Music / Science-Mathematics / Technology-Engineering)

In this first phase students become interested in the subject they are going to deal with. It is a very important step because it is here that pupils will start their 'expedition' into the STEAM world. This phase includes:

- wonder, ask questions, explore, observe
- identify problems, questions and chances
- relate to background knowledge.

Questions can be quite general, but also more convergent to a specific problem. These questions will guide further the development of the learning process.

The 'engagement' can happen in all of the STEAM 'worlds'. From which world one enters, can depend partially on the student's preference, but is also depending on the structure of a chosen scenario. It is crucial that in a scenario concepts from one or some different fields, are translated into some situation, problem or question. In [appendix 2](#) the concepts are illustrated in the form of concept maps based on the educational scenarios. We will give here some first general outlines about how this 'engagement' phase could be in the different fields:

### ***STEAM Music***

Students could listen to music. We can speak about observation by listening to music, to explore the different musical components (rhythm, melody, harmony, structure, tempo, timbre...) and to pose questions about it. To start an expedition into the musical world. But in order to understand these musical concepts more through, they have to complement their musical exploration soon with related scientific and/or technological questions. For instance the height of a tone is musically related to the musical component of melody. But how tones of different height are produced on an instrument? What are the scientific concepts explaining high and low tones (M/S)? How we can make instruments to produce high and low tones (E/T)?

### ***STEAM Science-Mathematics***

The desire to understand is encouraged essentially by observation and exploration of phenomena that can be explained by some scientific concepts. For instance they listen for a second to a high and low pitched tone. From such an observation scientific questions are raised and the desire to understand the phenomenon in a consistent way is encouraged: if sound are indeed waves, how do waves of high tones differ from waves of low tones?

### ***STEAM Technology-Engineering***

By asking students to make music with some (primitive) technological object (for instance a primitive flute consisting of only a tube), students are engaged to make or improve some technical object. It could be a musical instrument but also a measuring instrument.

In case of a flute which consists only of a simple tube, students could for instance add a mouthpiece which contains an edge. Or the desire to play more than one tone can be triggered. Can we alter the length of the tube or are we going to add holes (at the appropriate places) to cause the same effect. In order to do so they need practical musical knowledge (field A) but also scientific one (S) like for instance the relation between length and pitch.

## **2. Imagine (Music / Science-Mathematics / Technology-Engineering)**

Once students become interested in the subject, they start dealing with the 'problem'. Let students become aware of different aspects of the problem, helpful to construct another view from a different discipline or a deeper view in the same discipline: backgrounds and concepts that might be at stake here, from one or different disciplines. First back and forth analyses (like when something changes another thing changes as well), first conceptual analysis, relations between concepts, relations between concepts of disciplines.

So the students explore together, pose questions. The role of the teacher is limited: organise and give time to sort out the problem, pose some questions with that purpose.

They use their imagination to make first hypotheses, first predictions, which can lead to further investigation in the next phase. Imagination has to do with constructing a differentiated conceptual view useful for further investigation or design.

Thus this phase includes:

- identify relevant variables to investigate – Identify Relevant Solutions to use;
- use your imagination and make hypothesis – Choose potential solution.

### **STEAM Music**

In the music world *imagine* is about distinguishing the musical components and identifying them. Constructing a richer view on music because of the discovery of these musical components. It is also about using the *inner imagination* to create something musical given this new look upon music.

### **STEAM Science (Science and Mathematics)**

In the science-mathematics world *imagine* has to do with constructing a conceptual view in order to form first explanatory hypotheses. It is crucial for understanding:

- Use their scientific *imagination* to **construct** deeper explanatory **concepts** which could underlie the phenomenon (preferably consistent with explanations/models already given).  
Example: Can sound be waves? Then sound waves propagate because waves do. But waves originate by some cause. For instance the wind for waves on the water. But what are the sources of sound waves?
- Use their *imagination* to make (first steps to create) a first scientific-mathematical **model with explanatory power**, preferably consistent with models and concepts already used. Bring an accepted concept or model further by applying it at a new phenomenon.  
E.g. with the known model of waves, apply it further in order to explain new phenomena like overtones.
- Imagine and identify which **variables** can affect a certain phenomenon and in which way.  
E.g. Imagine which boundary conditions make an aerophone sound higher? Thickness of the tube? Length of the tube?

They are encouraged to explain with this concepts, models and possible variables the phenomenon in a consistent way (see next phases).

### **STEAM Technology-Engineering**

In the technology-engineering world *imagine* is about making hypothesis about the working of a certain object, or the properties of certain materials, etc. It is also about *imagining* how to use these understandings to improve or to create something.

## **3. Create – Investigate/Design**

Once imagination has done its work, it is time to actually create or investigate something. This phase can be subdivided into two steps, where specific actions take place depending on the specific STEAM world:

- Think of an investigation along the concepts and models (Science-Mathematics) you have explored in the previous phase.  
Or, Design the prototype along the guidelines of components and working models you've imagined in the previous phase (Music / Technology-Engineering).
- Carry out the investigation (Science-Mathematics), verify the model, apply the concepts.  
Build the prototype along the guidelines of the previous conceptual work (Music / Technology-Engineering).

### **STEAM Music**

To *design* a musical expression you need a melodic pattern, a musical form, a modus, a time signature (two beat or three beat). Building a prototype of a musical instrument requires musical understanding as well as a positive attitude for technology and engineering.

### **STEAM Science (Science and Mathematics)**

In the world of science and mathematics *creation* is linked to *investigation* to understand. This is also a creative process, but with some different, specific accents. Typically is to create representations, create, apply and adapt models. When explaining something, modeling and theory is at stake (Tiberghien, 2000). In the iMuSciCA context, the investigation will lead to a scientific/mathematical understanding of music, which will support the creation of a musical instrument and a musical composition.

### **STEAM Technology-Engineering**

In the world of technology and engineering, as in that of music, we can rather speak about *designing* and *building* something as a result of the creative process, instead of *investigating* to understand.

## **4. Analyse**

Analysing means giving a meaning to what has been found or built, by relating it to the initial observations, concepts, models and background knowledge. Also in this case we can make a distinction between analysing in science-mathematics, in music and in technology-engineering:

- Analyse Data from Investigations (Do they verify the proposed model? Did we interpret the concepts in a sound and consistent way?), draw conclusions or make generalisations (Science-Mathematics) / Evaluate the Prototype (Music / Technology-Engineering).
- Explain by Relating to concepts, explanatory models and consistency with background knowledge (Science-Mathematics).
- Optimise the prototype (Music / Technology-Engineering).
- Describe and explain the results in the different STEAM-fields and the connections between them (all disciplines).

In contrast to the next phase (communicate and reflect), we speak here about a reflection on the results and the process: the individual or the group of collaborating persons, which made the investigation or built the prototype, reflect by:

- analysing the data, judge the logic validity of the proposed hypothesis or model. Coming to sound conclusions (Science-Mathematics)
- making an evaluation of the creation and, if needed, optimising it (Music / Technology-Engineering)

Although the creation phase is mostly within one discipline, it is imported to repeat the cycle and take the opportunity to go back to an imagination phase but within the view and concepts of 'another discipline'. Build a new phase of creation as consequence around the same phenomenon or component, but this time in that another discipline. In this way students will learn to look upon the same with different concepts and tools. They will discover relations and connections between the different disciplines who will look upon the same with a different language and a different conceptual framework. After the work is done, it is important to look back at the process and be aware of the way in which these disciplines interacted and how their views, concepts and practices are complementary to one another. The results of this are taken to the next phase as well.

## 5. Communicate and Reflect

The difference between this phase and the previous one, consists in the source of reflection, which corresponds in this case with the external world. As real scientists, engineers and musicians do, pupils will be invited to *communicate* their results and products. This will lead also to get feedback, which in its turn will lead to further reflection, optimisations if needed, and for sure the incorporation of that feedback in future work (i.e. elaborate and transform it into something useful). We distinguish here the following steps, with specific accents for the different disciplines:

- Communicate Results and Conclusions (Science-Mathematics) / Communicate the Product, Perform (Music / Technology-Engineering)
- Reflect on Feedback and incorporate it in further processes (all disciplines)

As indicated in the iMuSciCA STEAM-pedagogy, these phases will be made explicit on the iMuSciCA learning environment, to the teachers and to the pupils as well the idea is to trigger their awareness concerning the learning process they go through.

The scheme of inquiry phases is a *model* of the inquiry process. Not every inquiry follows exactly this scheme. It may so happen that certain phases can be repeated several times in a lesson or scenario and not always in the 'right' order.

This freedom in the order of phases in an iMuSciCA activity reflects the open way real investigation occurs because, as the history of science shows us, inquiry follows many times rather unexpected paths (Matthews, 1994). Science, Music, Technology are all human collaborative activities where inspiration and diverse sometimes unexpected pathways are as important as a strict disciplinary methodology. It is this diverse and interdisciplinary field of STEAM that iMuSciCA wants to show. Since there is little both empirical and conceptual work that has guided interdisciplinary STEAM-based teaching practices (Kim & Park, 2012a, 2012b; Yackman, 2008), iMuSciCA could give some input on that as well.

# Appendix 4 - How to connect iMuSciCA's to the national curricula in France, Belgium and Greece

Joining science, technology, engineering, mathematics and art is far from evident also from the curriculum point of view. So iMuSciCA is fostering renewal on this point too. That's why we investigate the possibilities in the current curriculum to connect iMuSciCA's innovative STEAM pedagogy with the existing curricula in France, Greece and Belgium. We give for each country some synthesis.

## 1. In France

France: Lower cycle of secondary: cycle 4 (12 to 15 year-old students).

1. In **Music** attention is given to musical expression, musical components like pitch, timbre etc. which all connect to iMuSciCA. Even the physics and acoustics of sound are mentioned.
2. In **Physics** attention is given to skills like inquiry, using digital tools and numerical modeling. Sound is mentioned as one of the subjects with concepts like frequency, duration, propagation.  
It is remarkable that under 'crossings between teachings' the *connection with art and music* is mentioned!
3. Under **Technology** there are learning objectives like 'design under constraints', 'realizing objects', which is exactly what our iMuSciCA students will do when they design a virtual (and based on that) consequently possibly even a real instrument ('prototype' as is mentioned in the curriculum). The curriculum even aims at connecting three dimensions (a bit like we do in iMuSciCA): the engineering dimension, the socio-cultural dimension (which is in our case 'Music') and the scientific dimension (where the laws of mathematics and physics are mentioned explicitly). Under the title 'modeling and simulation of objects' computer simulations based on theory is also very appropriate for iMuSciCA. Also here crossings with art and music are mentioned!
4. Under **Mathematics** there are possibilities within the intended 'collaborative work' and 'research activities' where also the connection with physics is mentioned. For instance, determining the influence of the length and modeling it in a formula, could be an appropriate research activity here.

An important reform of primary school and middle school curricula has recently taken place in France leading to the implementation of new curricula in France in September 2016. This reform introduced in particular the "Interdisciplinary Practical Teaching" (Enseignements Pratiques Interdisciplinaires) for grades 7, 8 and 9 (12 to 15 year-old students). In these workshops, the students must carry out a project in small groups involving several subject matters on the same theme. The workshops are under the responsibility of a team of several teachers of the subject matters the project deals with. The students must attend at least two such workshops in a year. An example involving music and sciences on sound is presented by an institutional site at the address [http://cache.media.eduscol.education.fr/file/EPI/54/0/RA16\\_C4\\_EPI\\_sons\\_555540.pdf](http://cache.media.eduscol.education.fr/file/EPI/54/0/RA16_C4_EPI_sons_555540.pdf)

As this type of class is recent, the iMuSciCA project provides a very appropriate opportunity of contributing to the implementation of the French educational reform.

Some changes in the reform may be done in France by the new Ministry of education making interdisciplinary teaching no longer compulsory. However the content of teaching will remain unchanged and still compatible with the learning of science and maths around sounds through music, especially as the new French Ministry wants to support strongly the learning of music. European projects like the iMuSciCA project may make the new French people in charge of education aware of the interest of STEAM projects

#### France: Higher cycle of secondary: lycées (15 to 18 year-old students)

Mainly in the physics courses of the 10th grade, where ‘periodic signals’ are an item on the curriculum itself, teachers could work in class with iMuSciCA. For other classes the link is somewhat more diffuse. In Music there are some opportunities too, but music is not found in every school and is many times optional.

#### **Conclusion for France:**

The French curriculum for upper secondary seem to give 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. The challenge is to make them see the possibilities of iMuSciCA’s STEAM-pedagogy.

## **2. In Belgium**

We will describe the curriculum as it is found in schools in Flanders and in schools of the Flemish Community in Brussels. In a later phase also schools of the French speaking community will be invited to iMuSciCA.

#### Belgium: Secondary school 1st stage (Middenschool) – 2nd year (12-14 years-old):

##### *1. Subject “Wetenschappelijk werk” – 3 hours/week*

There is a context ‘*licht en geluid*’ *Light and sound* where attention is given to

- Vibration as source of sound
- Sound propagate as a pressure wave through a medium

##### *2. Subject “Muziek” – 1 hour/week :*

Attention is given to :

- 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

##### *3. Subject “STEM”:*

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.

#### Belgium: Secondary school 2nd stage (15 -16 years-old):

1. *Subject “Biology”*: 3 - 4 lesson hours on *sound and hearing* in the first year.  
There is an activity about how you can hear the harmonics in a tone (by resonance of the appropriate hairs in the cochlear)
2. *Subject “Muziek”*: 1 hour/week
  - Focus on: play music individually and in group
  - Music in different cultures: different musical scales
3. *Subject “STEM”*:  
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.

#### Belgium: Secondary school 3rd stage (17-18 years-old):

Subject “physics”: *waves and vibrations*, 11-18 hours in the last year of secondary.

- Eigenfrequency: 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
- wavelength, 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.

Some schools have an seminar where the students work typically in small groups on an Interdisciplinary subject on an inquiry manner. Very suitable for iMuSciCA.

#### **Conclusion for Belgium:**

For iMuSciCA there are possibilities both in the 1st stage as in the 3rd stage. Opportunities in the 2nd stage are somewhat more restricted. Especially the new subject STEM which many schools in the 1st stage setup, might be a good environment for piloting iMuSciCA. The challenge is to make teachers see the possibilities of iMuSciCA’s STEAM-pedagogy.

### **3. In Greece**

The curriculum in Greece allows in-classroom interventions according to the curriculum described in the following part of this section, as well as interventions in terms of school clubs which take place both in junior and senior high school throughout the school year with a duration of a few hours per week.

#### Greece: Primary school (Grades : 1-6 , age: 6-12 years old)

1. *Subject “Physics”*  
Pupils should be able to understand basic Characteristics of Sound. How the sound is produced along with some basic sound features. The means to achieve this is through interaction. Additionally an interdisciplinary curriculum is encouraged in primary school. “Technology” and “Physics in everyday life” as interdisciplinary subjects are included.
2. *Subject “Music”*  
Selected abilities related to iMuSciCA that should be developed in primary school can be summarized as follows.



In lower primary, 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.

In upper primary, except the above tasks, pupils learn how to:

- 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.

#### Greece: Lower Secondary education (Grades : 1-3, ages: 12-15 years old)

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.

##### 1<sup>st</sup> grade of Junior High School

###### *Subject "Mathematics"*

- Chapter on equations
- Chapter on triangles and geometric shapes

##### 2<sup>nd</sup> grade of Junior High School

###### *Subject "Mathematics"*

- Chapter on functions and graphs
- Chapter on geometric solids

##### 3<sup>rd</sup> grade of Junior High School

###### 1. *Subject "Mathematics"*

- Chapter on equations of the 2nd order
- Chapter on geometry
- Chapter on trigonometry

###### 2. *Subject "Physics"*

Students learn about oscillations, waves and acoustics. They also learn how to:

- Link the wave to the propagation / transfer of energy.
- To recognize the mechanism of propagation of a mechanical disturbance in a material and to describe the characteristics of the propagation.
- Identify and describe the characteristics and properties of the sound.
- Period, Frequency, periodic phenomena
- Link the sound wave with energy transfer.
- wave equation, propagation in different media, empirical characteristics of sound.

###### 3. *Subject "Music"*

Selected abilities related to iMuSciCA that should be developed in primary school can be summarized as follows.

In lower primary 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.

Greece: Upper Secondary education “Lyceum” (Grades : 3-6)

1st Grade of Senior High School

*Subject “Mathematics”*

- Chapter on Equations
- Chapter on functions

2nd Grade of Senior High School

*Subject “Mathematics”*

- Chapter on Trigonometry

3<sup>rd</sup> grade of Senior High School (17 year olds) :

*Subject “Physics”*

- Chapter on Physics of Oscillations
- Chapter on Physics of waves
- Equations, Wave Superposition, Standing Waves, Doppler Effect, sound.

Greece: Secondary Music Schools (Lower & Upper Grades : 1-6, ages: 12-17 years old)

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 1<sup>st</sup> and 2<sup>nd</sup> 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.

**Conclusion for Greece:**

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 3<sup>rd</sup> grade of Junior High School and the 1<sup>st</sup> 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.

## Appendix 5 - Support for using the iMuSciCA workbench

For each iMuSciCA activity environment we report here a short guide to support the users (teachers and students) while performing activities with the iMuSciCA workbench.

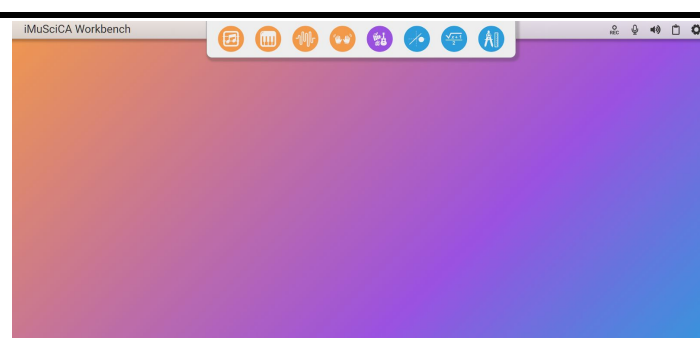
### Workbench Guide: iMuSciCA Activity Environments and Tools

Within each tool in the Workbench you have a number of tabs that you can use to measure, among other things, the waveform and frequency of your music pieces.

Open the iMuSciCA Workbench with the following link:

<https://workbench.imuscica.eu>

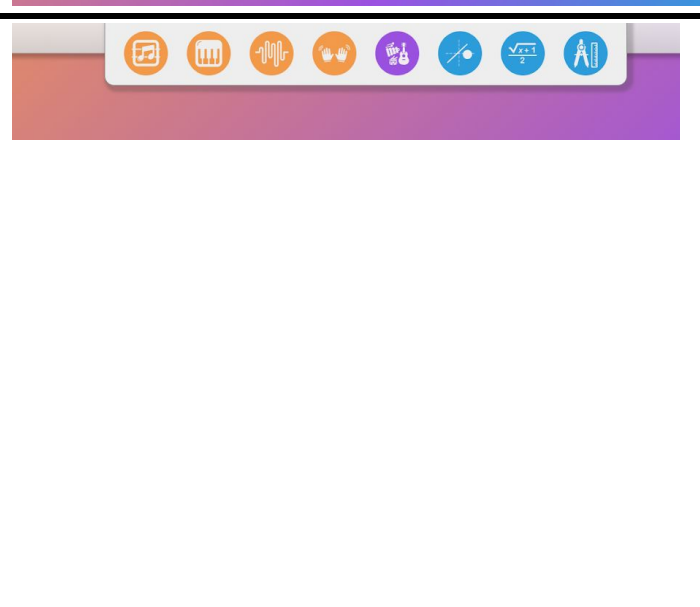
The following page appears



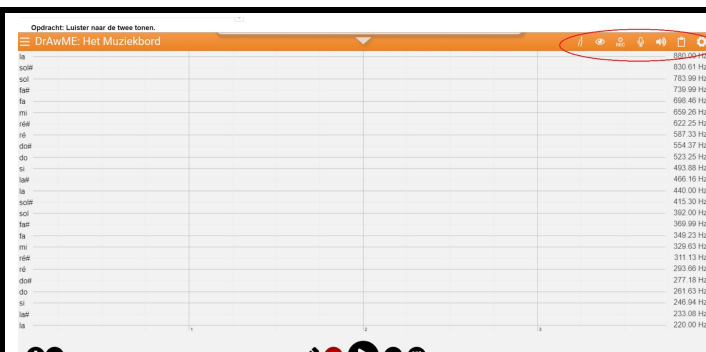
There are 8 iMuSciCA *activity environments*. They are reached by clicking on the top center arrow. You will discover:

- 1) DrAwMe: The Musical Whiteboard
- 2) Performance Sampler
- 3) Tone Synthesizer
- 4) 3D Instrument Interaction.
- 5) 3D Virtual Instrument Design.
- 6) Sonification
- 7) Math Editor
- 8) Geometry & Algebra

All these are described in more detail in separate sections further below.



Whenever you open one of these 8 iMuSciCA Activity Environments (for instance the DrAwME Environment), there will be more tools appearing at the top right site of your screen. These extra tools will function in combination with the 8 Activity Environments.



You can choose between one of the following extra tools:

- Music Tools
- Visualizations
- Sound Recorder
- Microphone
- Volume
- Clipboard
- Settings



### Music Tools

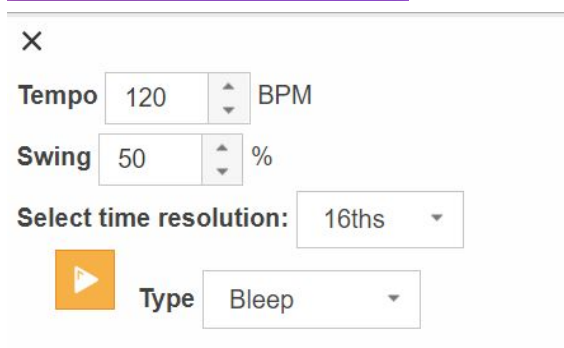
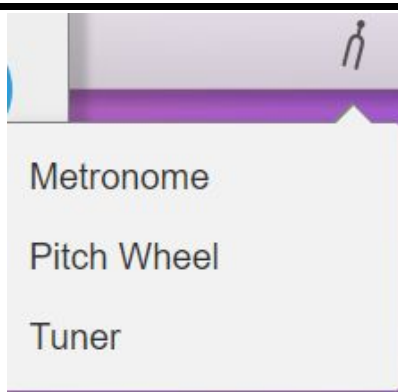
In the Music Tools you'll find the:

1. Metronome
2. Pitch Wheel
3. Tuner

You can alter the width of the tools window by dragging the left border.

The **Metronome** gives you control over 4 parameters

- 1) Tempo:  
Let's you alter the BPM or beats per minute the metronome plays
- 2) Swing:  
Alters the swing of the backdrop of the metronome, at 0% it's very monotonous and as you increase the percentage, the "swing" or rhythm increases. This only has effect with a time resolution of 16ths.
- 3) Time resolution
  - a) 16ths



b) 8ths

c) 4ths

This defines after how much time the metronome strikes:  
16ths/8ths/4ths of a second

- 4) Type: pick a Bleep or Tick sound

The **Pitch Wheel** lets you choose a reference tone to compare with. Combined with a visualization tool - which you can show above the Pitch Wheel at the same time - you can compare for example the sound of A# with its soundwave.

Thirdly the **Tuner** analyses the frequency and tone of any sound, in the workbench if the microphone is muted, from anywhere (any instrument, noise or song) if you unmute the microphone.

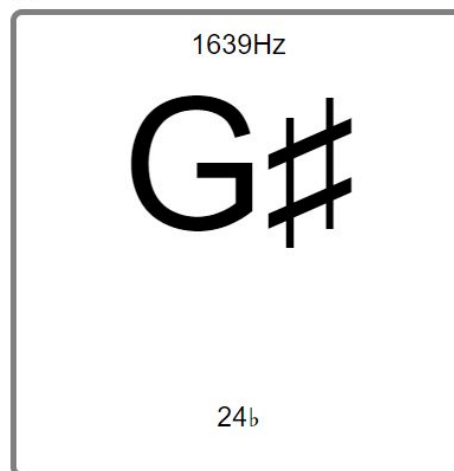
×



×



×



## Visualizations


1. 2D Sound Visualization
2. The Snail
3. 3D Sound Visualization

You can alter the width of the Visualizations window by dragging the left border.


**2D Sound Visualization** gives you three different ways to visualize sound:

- 1) Sound waves
- 2) Fourier spectrometer
- 3) Spectrogram


Click one of the squares on the right to choose which one you want to portray in the larger screen.

You can pause the recording by pressing the 'pause'  button. Press

 to start recording.

Press  to save a .json-file

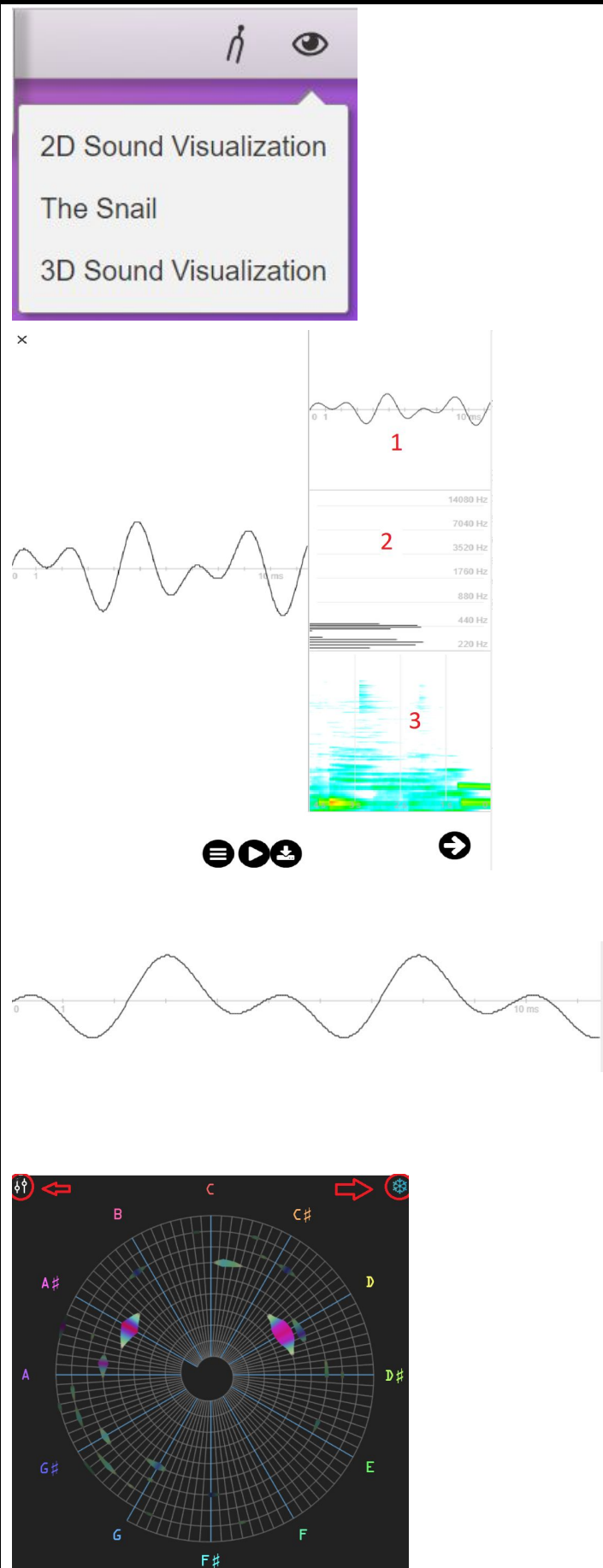
Sound waves show the wave produced by sound/noise. The axis is divided in milliseconds 'ms'.

Click  to hide the squares on the right.

## The Snail

In the snail you can see which tones you play. You can adjust settings in the top left corner and pause the screen in the right top corner.

The settings can be altered to specify which *input range* you'd like the Snail to measure.



*Visual gain* changes the sensitivity, left is less, right is more, it changes how much of the sound is visualized in the snail.

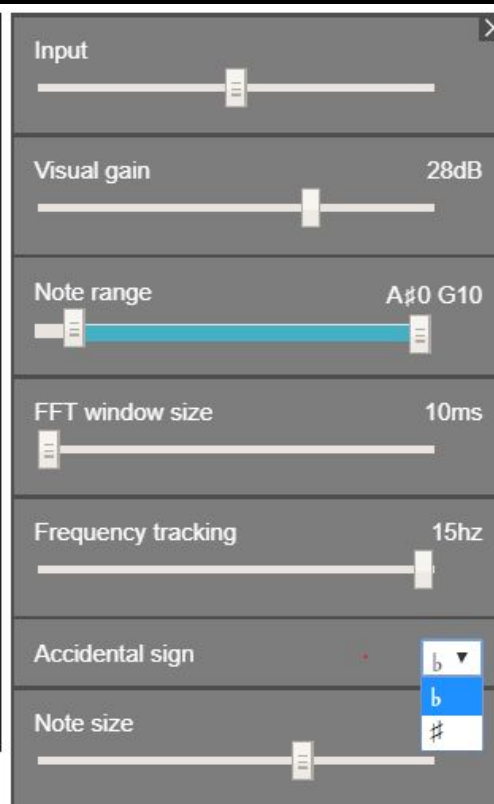
*Note range* defines in which range Snail is working.

*FFT window size* let's you specify how accurate the time frame in which snail works is. The smaller the time frame the more "accurate", but you could also see more "noise".

*Frequency tracking* defines the range of frequencies being tracked, left is less, right is more.

*Accidental sign* lets you choose between the two signs.


*Note size* alters the size of the notes from large to hidden.





### 3D view

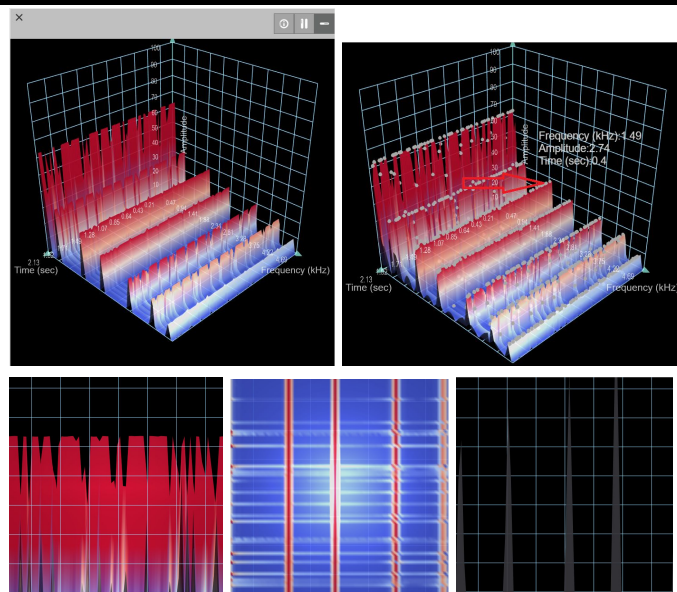
In the 3D view you can see the spectrogram (time-frequency) of the sound wave in 3D.

Through double clicking any of the three walls you can get a 2D view of either the Amplitude on the right, the Frequency (flat in the middle) and Time on the left wall.

The button  in the top right hides the grid.

The  button pauses recording.

Lastly does the  button show the peaks in grey dots, if you hover over this frequency, amplitude and time of this point are shown.



### The Sound Recorder

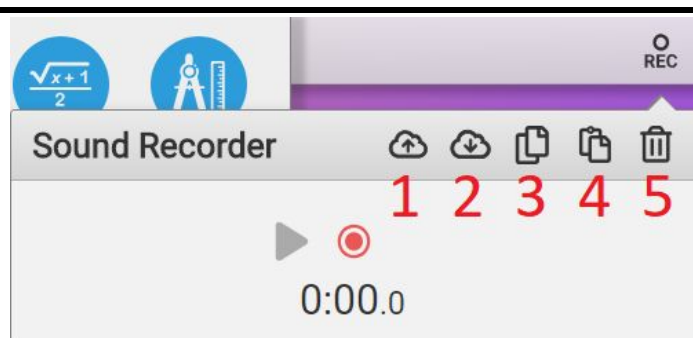


Press to start recording

Press to stop recording

Press to play your recording

- 1) Save your recording
  - a) Save Content to the cloud
  - b) Name is obligatory
  - c) You can save it privately just for you (default) or share it by "Make publicly available"
  - d) Cancel
- 2) Upload a recording
- 3) Copy to the clipboard
- 4) Paste from the clipboard
- 5) Delete recording



Save Content

Name

☐ Make publicly available

Cancel Save

Load Content

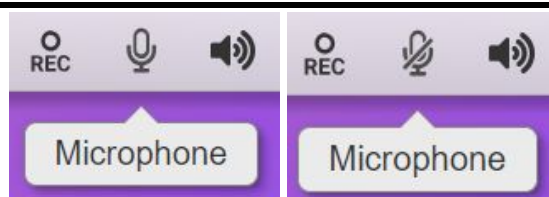
My classroom

Name	Creation Date
LALALA	03/07/2018 15:19:26
whistle3	03/07/2018 15:48:22
A880	11/07/2018 9:30:25
lipton	03/07/2018 15:41:08
mymicrecording	01/07/2018 10:05:43
1	02/07/2018 12:02:06
violin LA	04/07/2018 11:02:53
hand	03/07/2018 15:17:18
123	03/07/2018 15:22:08
lipton	03/07/2018 15:16:59
whistle2	03/07/2018 15:43:53
de	04/07/2018 15:19:07
myRecording	02/07/2018 14:19:15
...	...

Delete Cancel Load

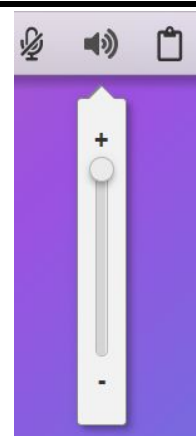
### Microphone

You can (un)mute the microphone to just use sounds from the workbench or also use external sounds.



### Volume

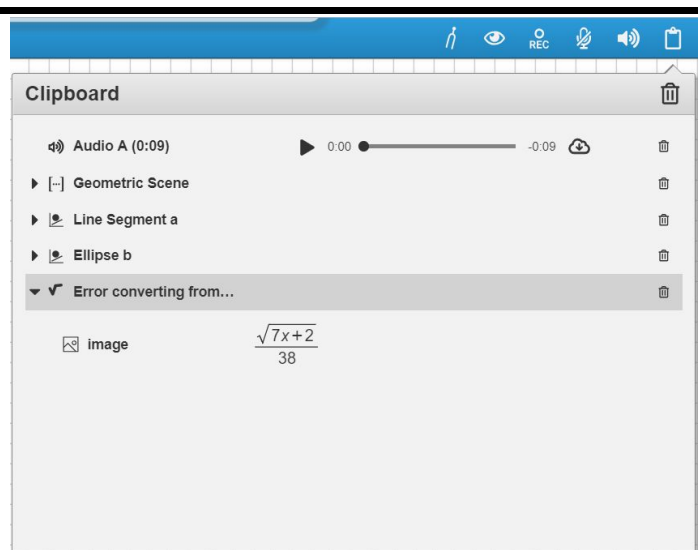
Increase or decrease workbench volume.






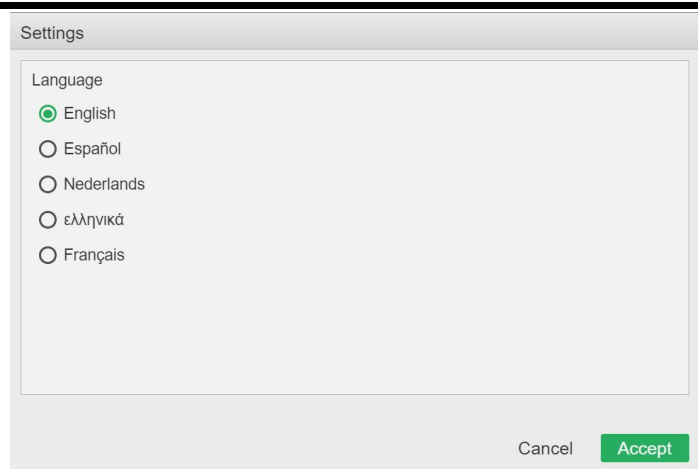
### Clipboard

In the Clipboard you can find audio, geometric scenes, segments, shapes, functions etc which have been copied and can be pasted from one activity environment to another.



### Settings

In settings  you can choose which language you'd like to work in.



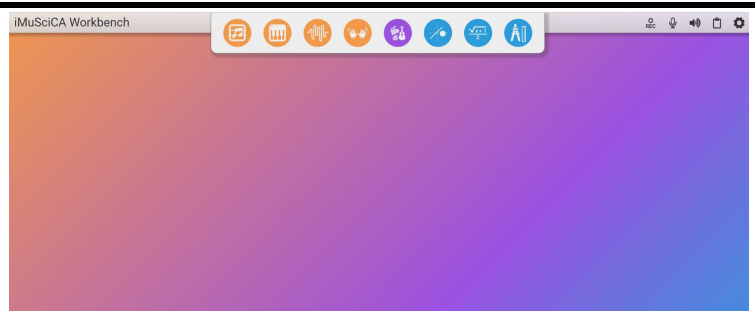
# Workbench Guide: DrAwME

The DrAwME tool is a tool that allows you to create a drawing that is converted into sound. You can use this tool in many ways.

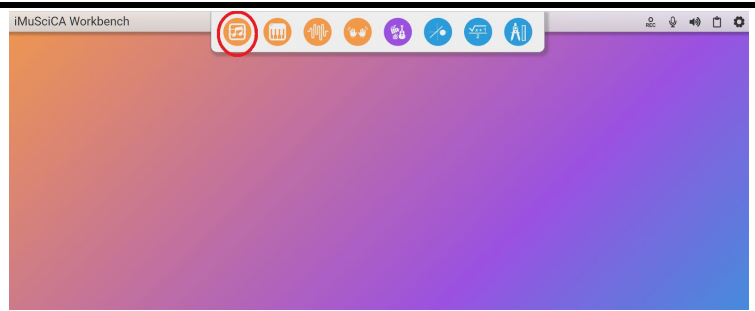
Open the iMuSciCA Workbench with the following link:

[workbench.imuscica.eu](http://workbench.imuscica.eu)

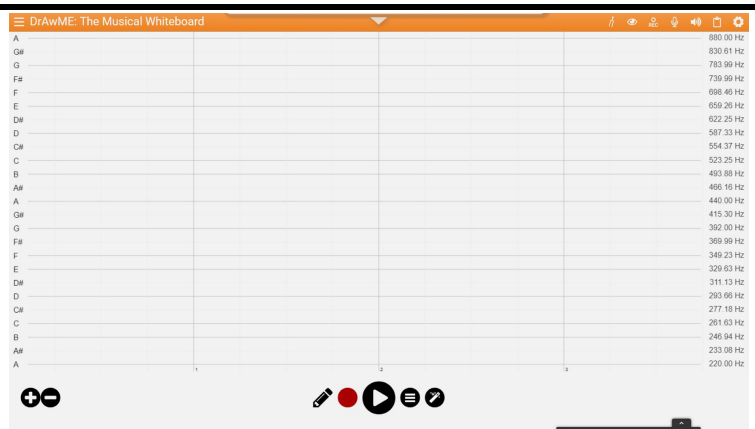
The next page appears



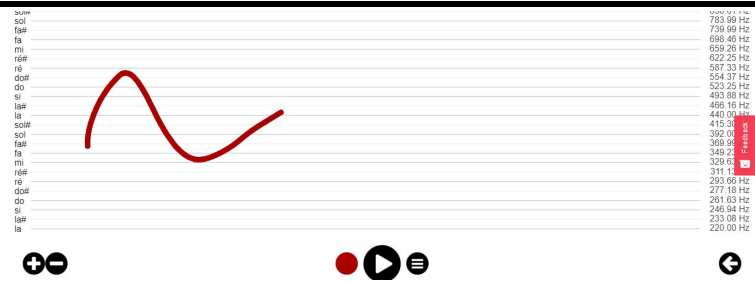
To open the DrAwME-tool<sup>1</sup>, click the music note.



The next page appears that includes a drawing canvas (area) which can generate music. Along the vertical axis (dimension) of the canvas, you can see the frequencies (on the right) and the respective music notes (on the left).

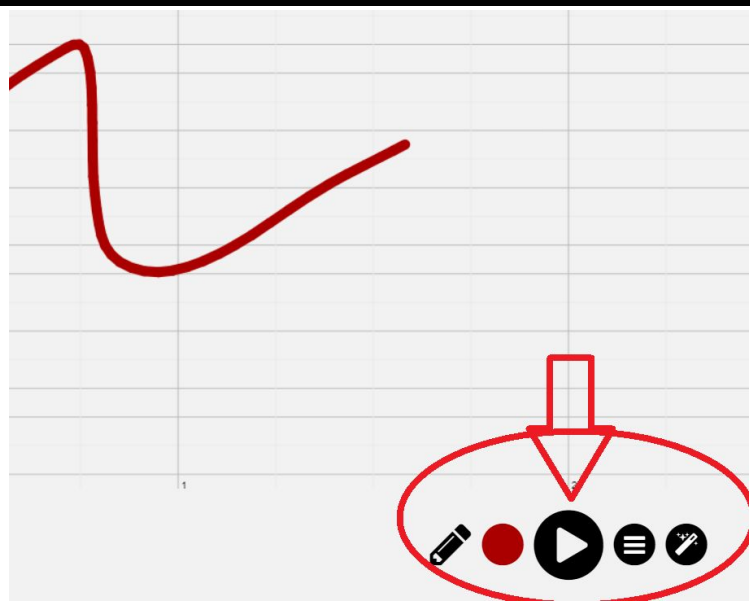


Hold the left mouse button (or use a digital pen) and move over the canvas. A line will appear following the trace of the mouse movement. You also hear the sound while drawing a line.



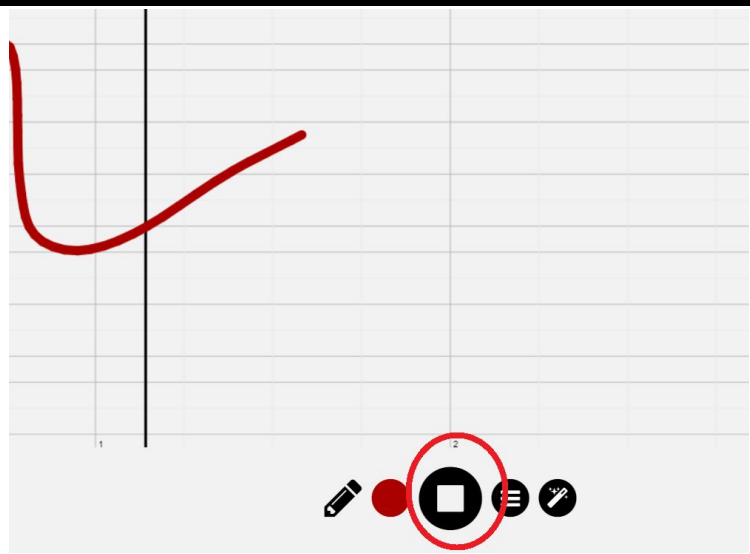
<sup>1</sup> From now on the term tool is used to refer to an activity environment

To play your piece of music, click on the play button.

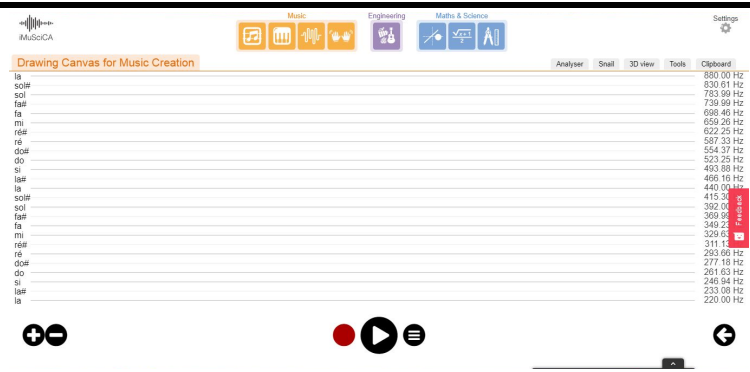


A black line will appear that tracks your piece of music over time.

To stop, click the start button, now converted in a stop button, again.



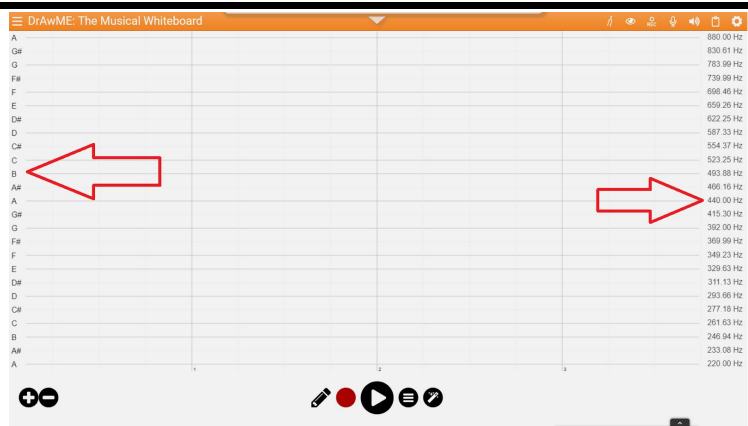
To remove one segment, position your mouse on the segment and click on the right mouse button.



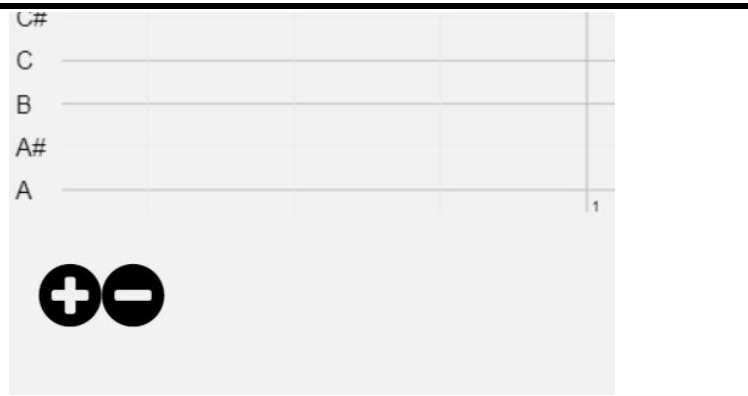
There are 2 different axis on the canvas.

Axis 1: the notes (sol, la, si, ...)

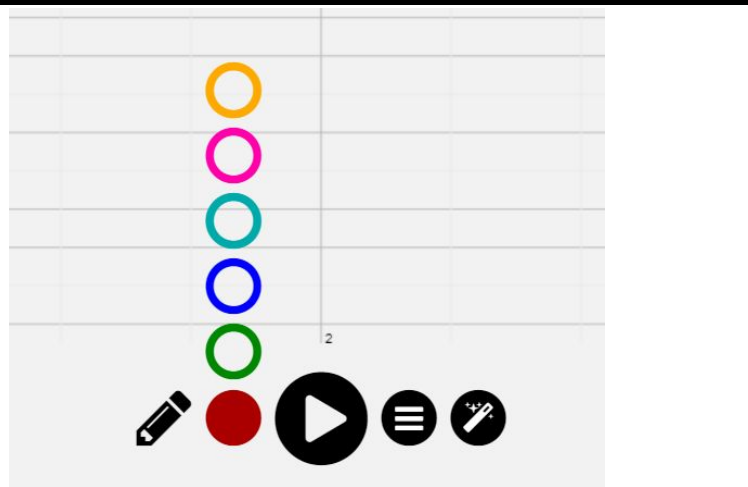
Axis 2: the frequency (Hz)



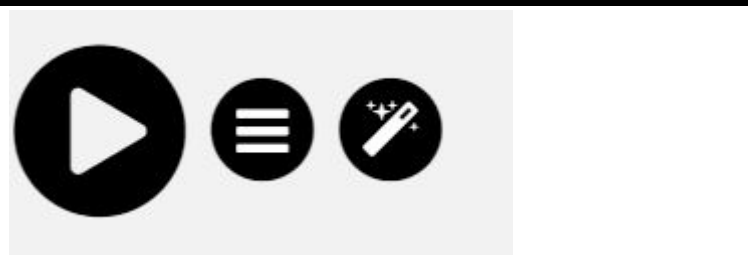
You can make your canvas larger or smaller by clicking on the '+' and '-' symbol at the bottom left.


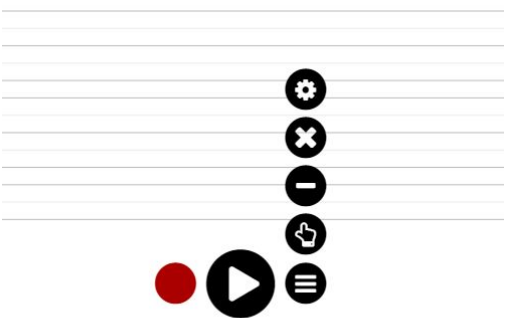
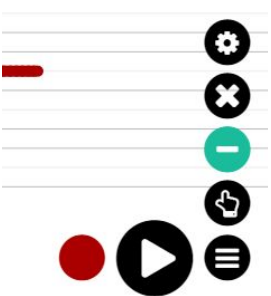








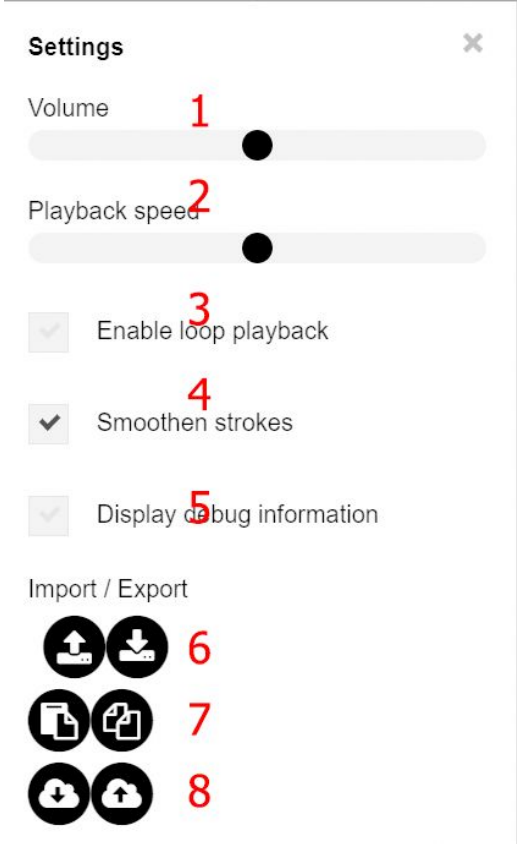
You can change the timbre of the drawing sound by clicking on the coloured button. You can choose from 6 different timbres (colours).



To select more options, click on the button with the 3 horizontal stripes.



<p>4 icons with symbols appear.</p>	
<p>By clicking on the hand icon, you choose to draw freehand. This option is set by default.</p>	
<p>By clicking on the line icon, you choose to restrict the drawing on the note frequencies (only horizontal lines allowed).</p>	
<p>By clicking on the x-cross, you remove everything that is on your canvas. Your canvas is cleared.</p>	

 By clicking on the gear, you open the settings.	
<p>The Magic Wand </p> <p>After selecting a drawing, line or figure with the , you can transform the selection by using the menu under the wand.</p> <ol style="list-style-type: none"> <li>1) Horizontal reflection</li> <li>2) Vertical reflection</li> <li>3) Unwind drawing</li> <li>4) Erase</li> <li>5) Copy</li> </ol>	
<ol style="list-style-type: none"> <li>1. You can adjust the volume.</li> <li>2. You can change the playback speed.</li> <li>3. You can have your piece played indefinitely in a loop.</li> <li>4. You can draw smoother lines. (checked by default)</li> <li>5. You can receive extra information about the location of your signed points.</li> <li>6. You can download or upload your piece of music.</li> <li>7. Copy your drawing to/from the clipboard.</li> <li>8. Save or load your drawing in the iMuSciCA cloud.</li> </ol>	

# Workbench Guide:

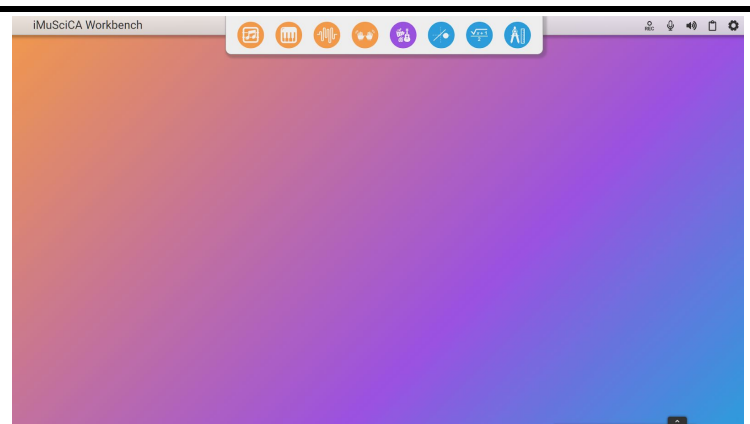
## Performance Sample Sequencer

The Performance Sample Sequencer can be used to create your own music by using samples from existing music pieces.

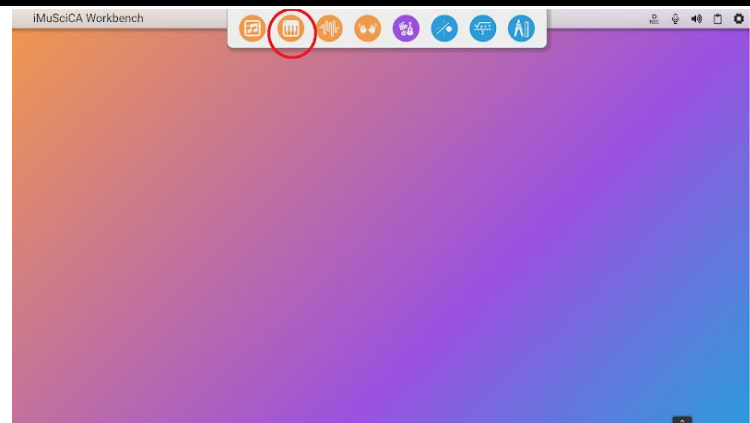
Open the iMuSciCA Workbench with the following link:

[workbench.imuscica.eu](http://workbench.imuscica.eu)

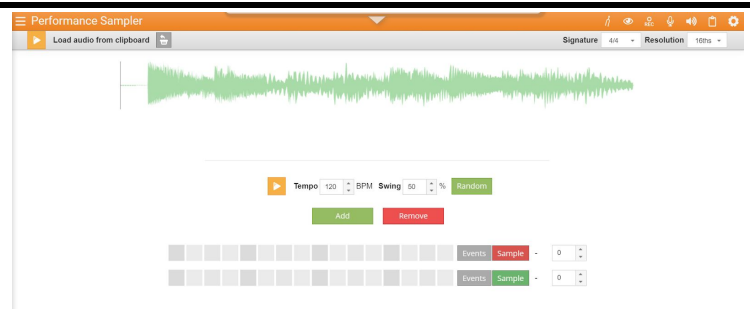
The next page appears



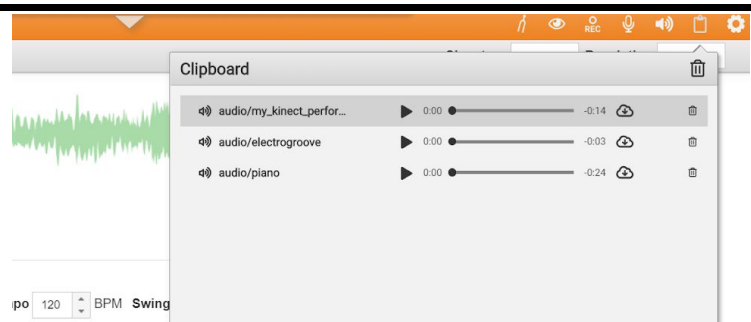
To open the Performance Sample Sequencer-tool click the piano-icon.



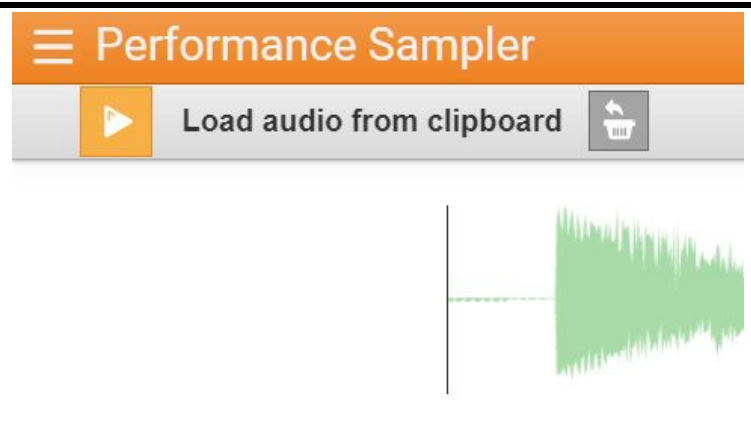
The next page appears:



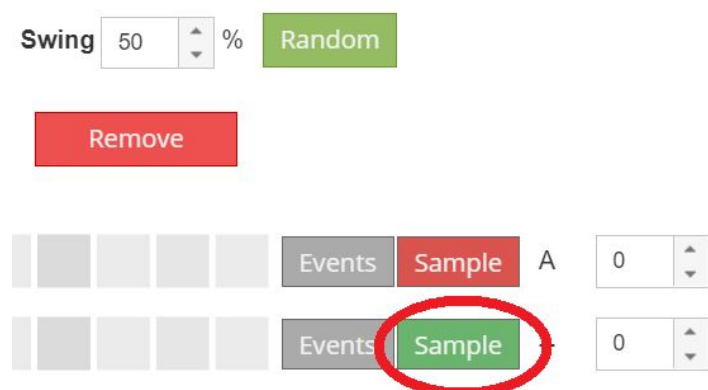
To choose a sound, click on 'Clipboard' and choose your sound or click on 'Load' from the iMuSciCA cloud.



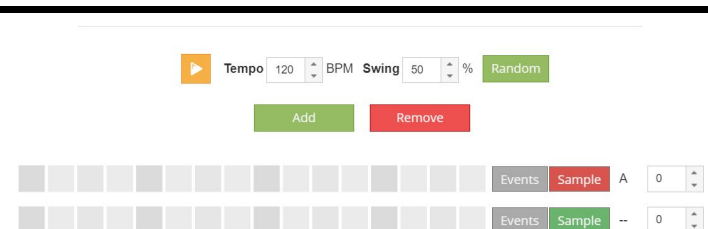
To play/pause the sound, click on the 'Play / Pause' orange button.



Select which sample you want to set by clicking on the 'Sample' button.

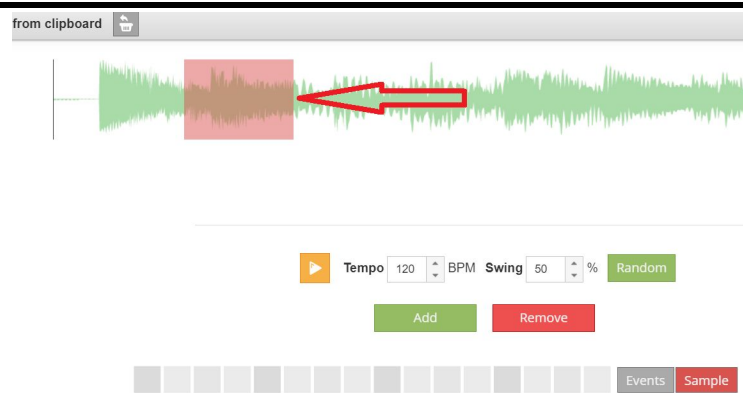


To add or remove a sample, click on green **Add** or red **Remove** buttons.

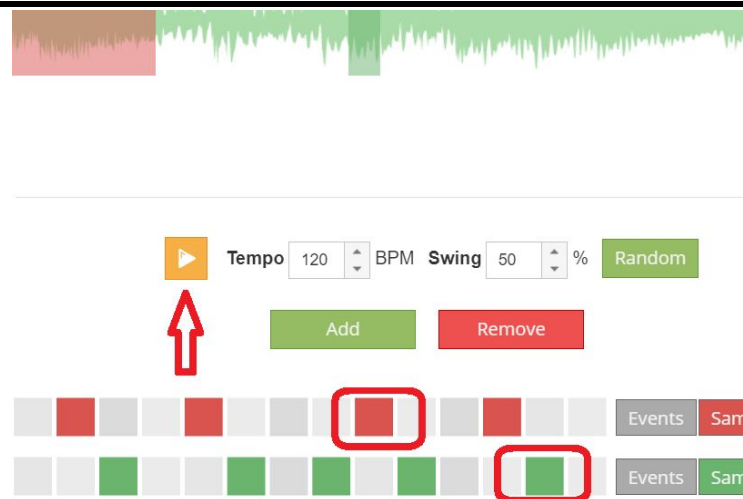




Once you have selected a sample, go to your sound clip and hold down the left mouse button to select an area.

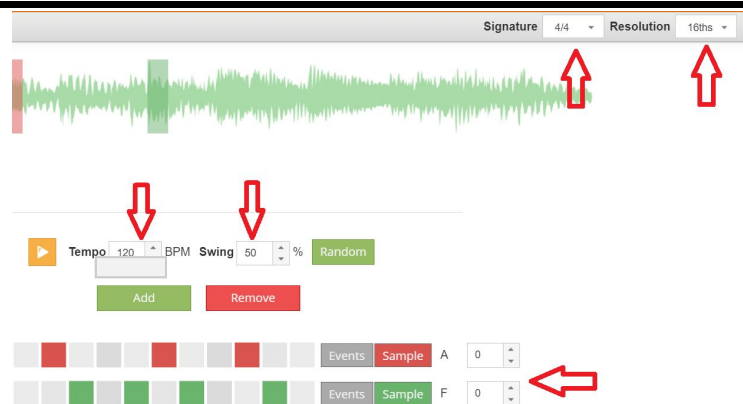


To create your music piece, click on the boxes to activate the selected sample. By clicking on 'Play', your music piece will be heard.



By moving the sliders, you can adjust the:

1. tempo
2. swing
3. pace
4. tone length
5. pitch



By clicking on 'Random', to generate random samples.



# Workbench Guide:

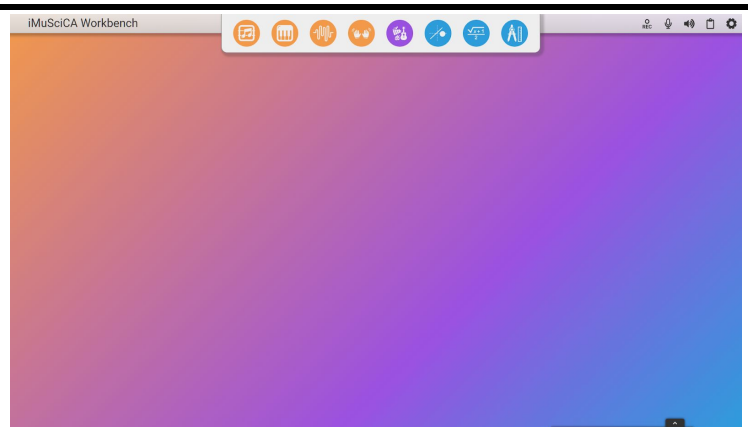
## Tone Synthesizer

The Tone Synthesizer is used to create composite/additive sinusoids waves.

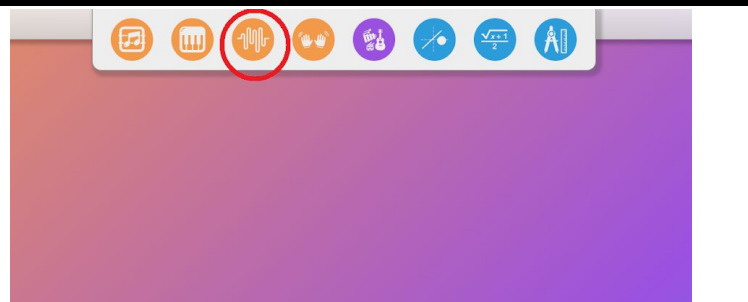
Open the iMuSciCA Workbench with the following link:

[workbench.imuscica.eu](http://workbench.imuscica.eu)

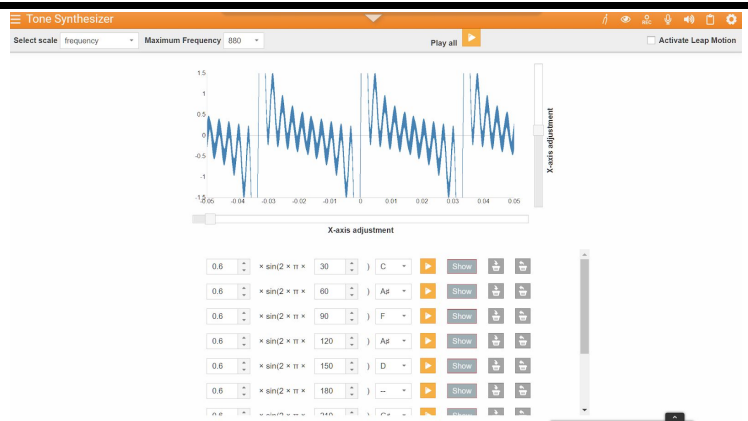
The next page appears:



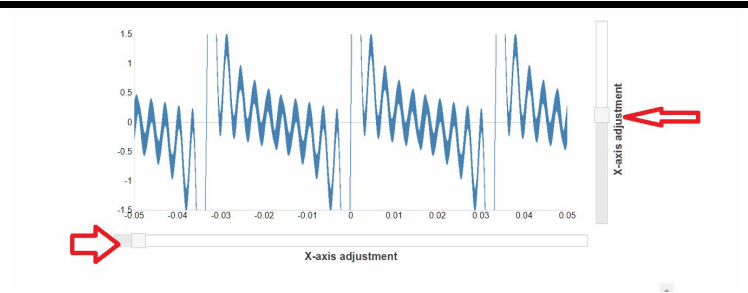
To open the Tones Synthesizer-tool click the orange icon of the waveform.



The next page appears:



You now see an x-y coordinate system. To adjust the scaling of the coordinate system, use the slides on the sides of the x-y axes.



To define a sinusoid, you have to enter the values of amplitude and frequency using the arrows or type the values of the respective boxes.

0.6  $\times \sin(2 \times \pi \times$    $)$  C

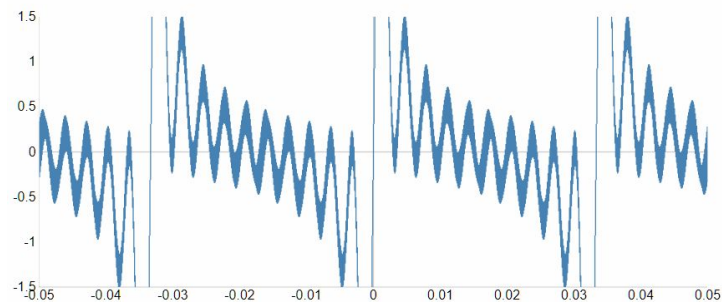
0.6  $\times \sin(2 \times \pi \times$  60  $)$  A#

0.6  $\times \sin(2 \times \pi \times$  90  $)$  F

0.6  $\times \sin(2 \times \pi \times$  120  $)$  A#

0.6  $\times \sin(2 \times \pi \times$  150  $)$  D

By adjusting the values, a wave will appear on the coordinate system.



By clicking on 'Play', the tone is played.

Clicking 'Pause' will stop the tone.

X-axis adjustment

( $2 \times \pi \times$  30  $)$  C

( $2 \times \pi \times$  60  $)$  A#

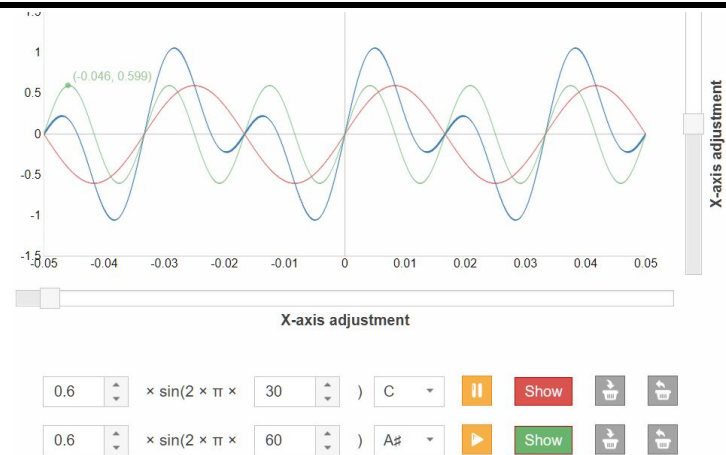
) C

) A#

\ F

By clicking 'Show', you will see the individual sinusoid waveform in the coordinate system.

The blue wave represents the sum of the red and the green wave.



istment

) C [Play] [Show] [Trash] [Trash]

) A# [Play] [Show] [Trash] [Trash]

You can also select a tone. By selecting a tone, the frequency associated with this tone will be entered automatically.

X-axis adjustment

Equation	Frequency	Phase	Play	Show
$\times \sin(2 \times \pi \times$	0	--	[Play]	[Show]
$\times \sin(2 \times \pi \times$	0	--	[Play]	[Show]
$\times \sin(2 \times \pi \times$	180	--	[Play]	[Show]
$\times \sin(2 \times \pi \times$	0	--	[Play]	[Show]
$\times \sin(2 \times \pi \times$	240	--	[Play]	[Show]
$\times \sin(2 \times \pi \times$	270	--	[Play]	[Show]
$\times \sin(2 \times \pi \times$	300	--	[Play]	[Show]

Tone Selection List:

- 
- C
- C#
- D
- D#
- E
- F
- F#
- G
- G#
- A
- A#
- B

# Workbench Guide:

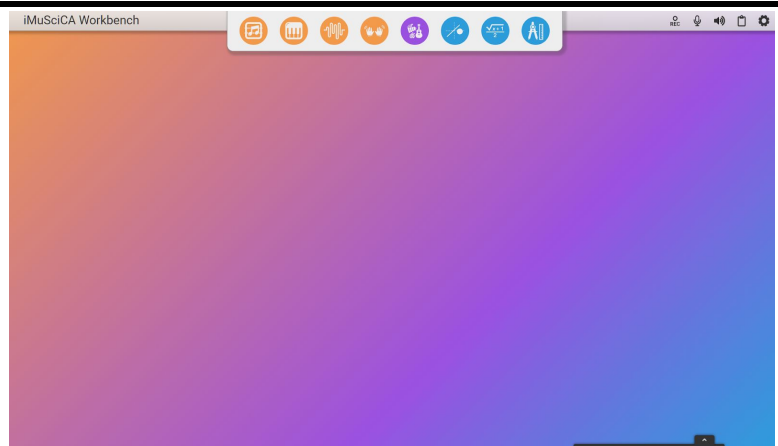
## 3D Virtual Instrument Design

You can use the 3D Musical Instrument Design tool to make your own instrument. By adjusting the length, thickness, tension and material of your strings yourself you can recreate a real instrument.

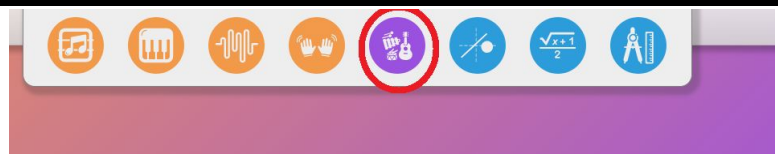
Open the iMuSciCA Workbench with the following link:

[workbench.imuscica.eu](http://workbench.imuscica.eu)

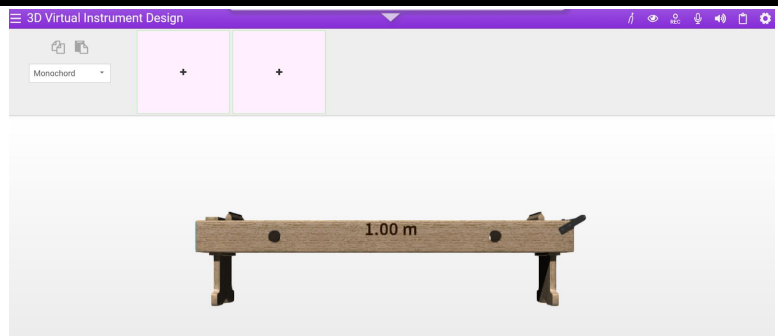
The next page appears:



To open the 3D Musical Instrument Design-tool click the purple music instruments icon.



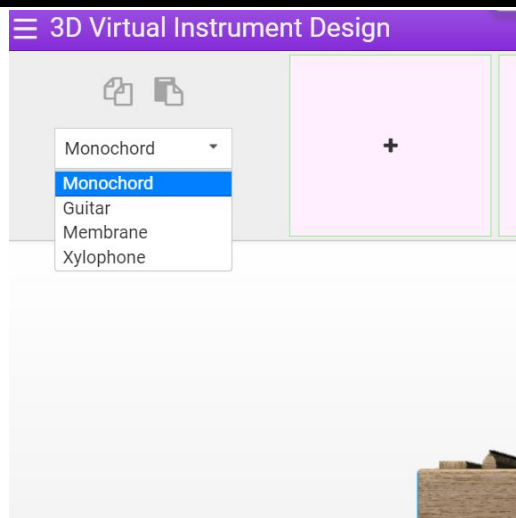
The next page appears:



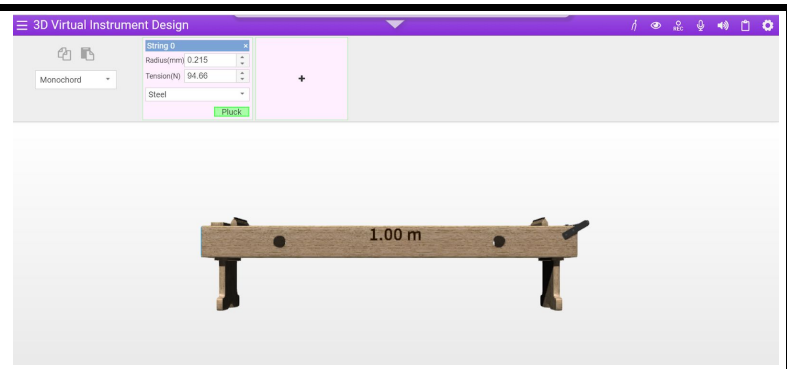
Choose your musical instrument by clicking on the down arrow which opens a menu..

You can choose among:

- Monochord
- Guitar
- Membrane
- Xylophone

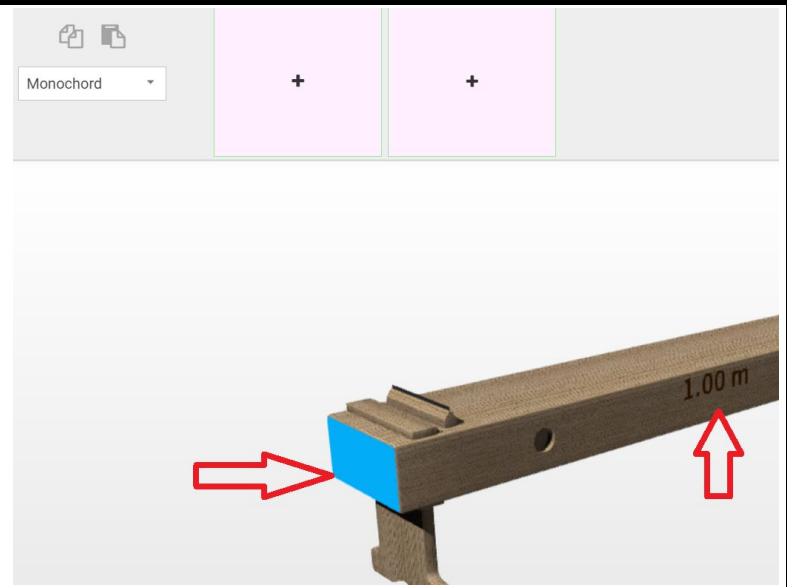


To move around your instrument, hold down the left mouse button while clicking on the instrument and move your mouse.



If you want to make your instrument longer, click on the blue surface and move your instrument.

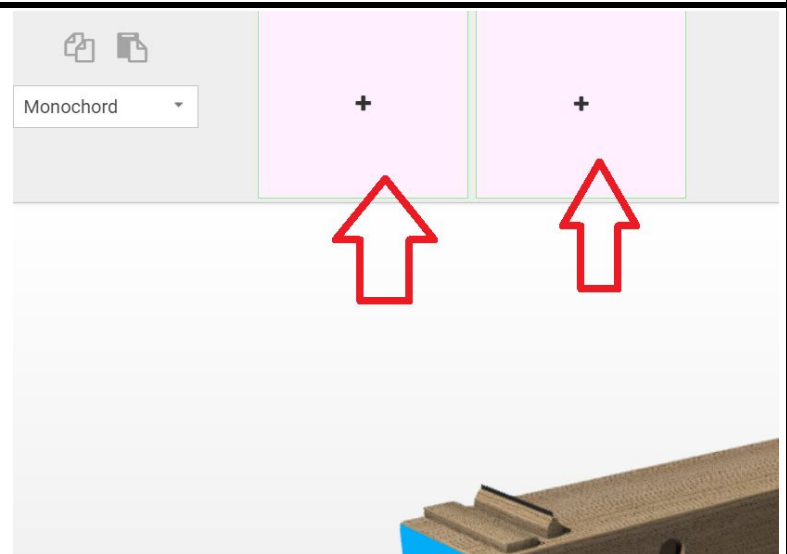
You can read the length on the instrument.



To add a string, click on the '+' box.

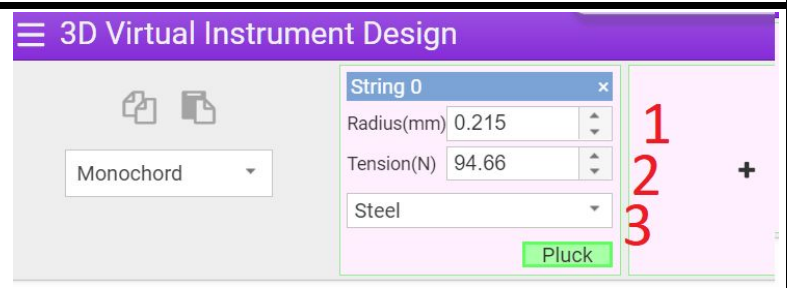
If you want to add a second string, click on the second '+' box.

The number of strings depends on the instrument.

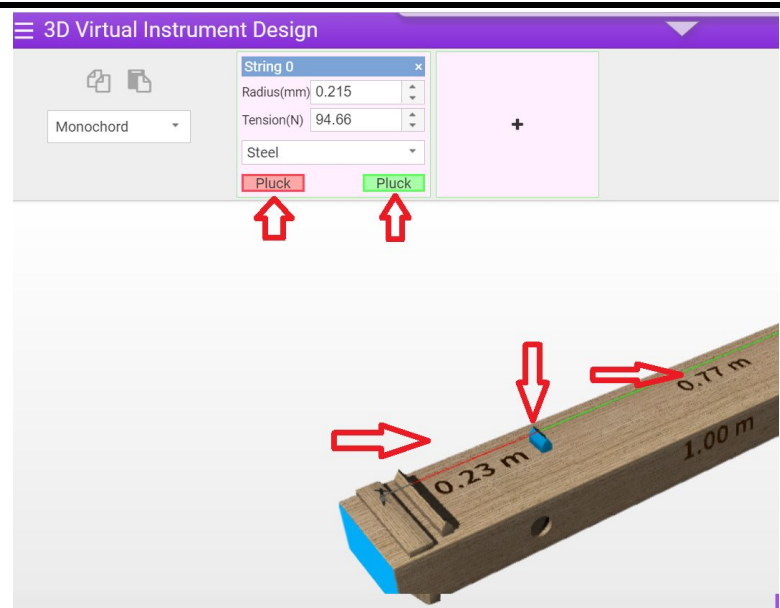


You can adjust a number of parameters:

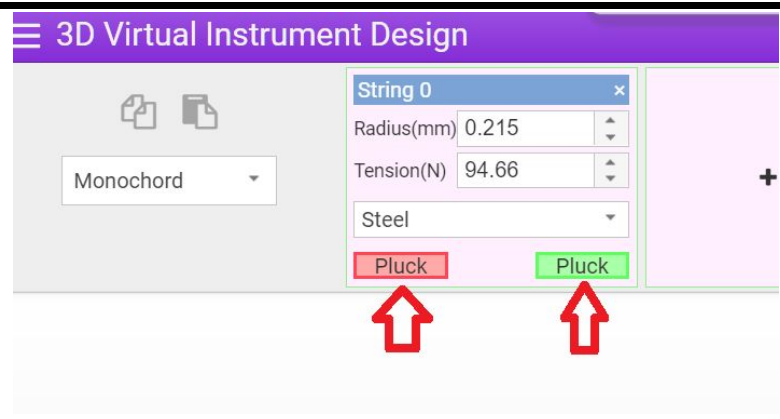
1. The thickness (radius)
2. The tension force
3. The material



You can reduce your string yourself by moving the blue bridge. There will be a new 'Pluck' button in the color of the string. This way you can play each part separately. You can see the length of each separate part written on the monochord.



By clicking on 'Pluck' your tone will be played.



# Workbench Guide:

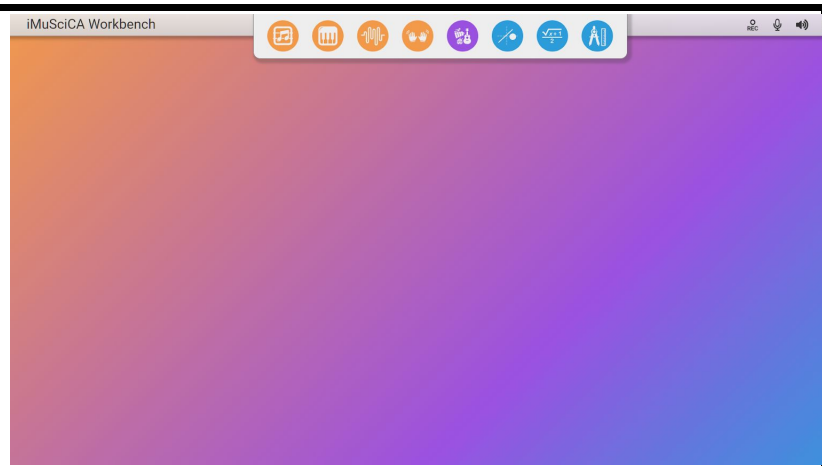
## Sonification of mathematical equations and geometric curves

The Sonification of mathematical equations and geometric curves can be used to draw functions. You can then hear how those functions sound.

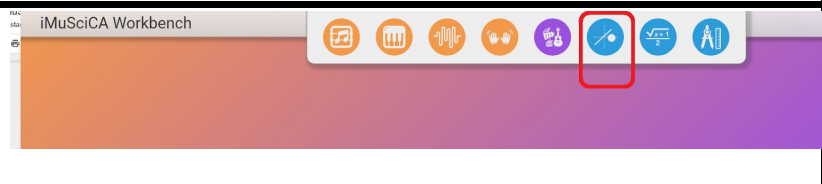
Open the iMuSciCA Workbench with the following link:

[workbench.imuscica.eu](http://workbench.imuscica.eu)

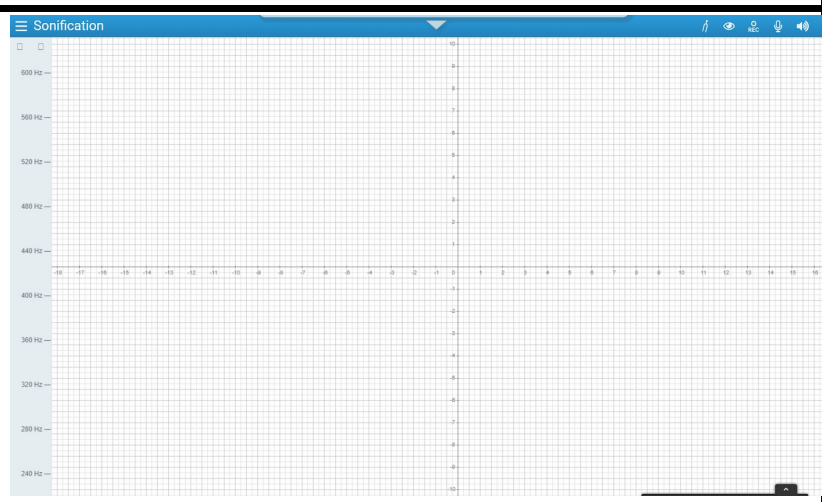
The next page appears:



To open the Sonification or mathematical equations and geometric curves tool, click on the blue coordinate system icon.



The next page appears:

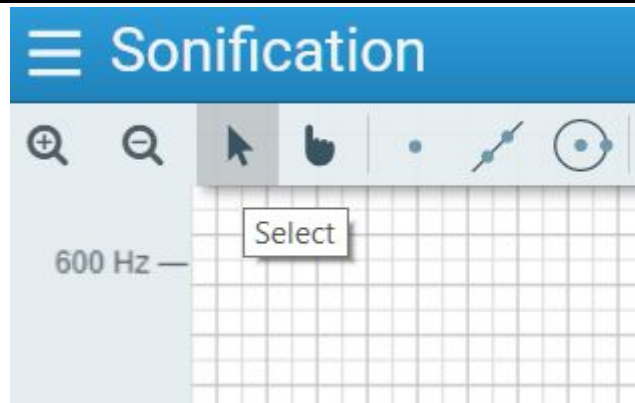




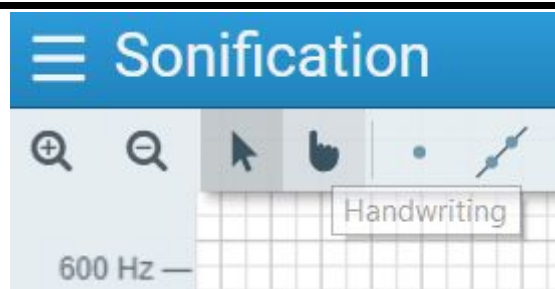
You can adjust the scale on the vertical axis by clicking on 'zoom in' and 'zoom out'



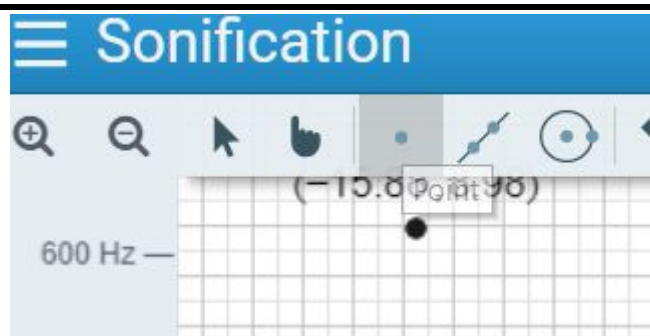
You can select an object by clicking on 'select'.



You can manually draw a graph by clicking on 'handwritten'



To draw a point in the coordinate system, click on 'point' and then click on the spot where you want your point.

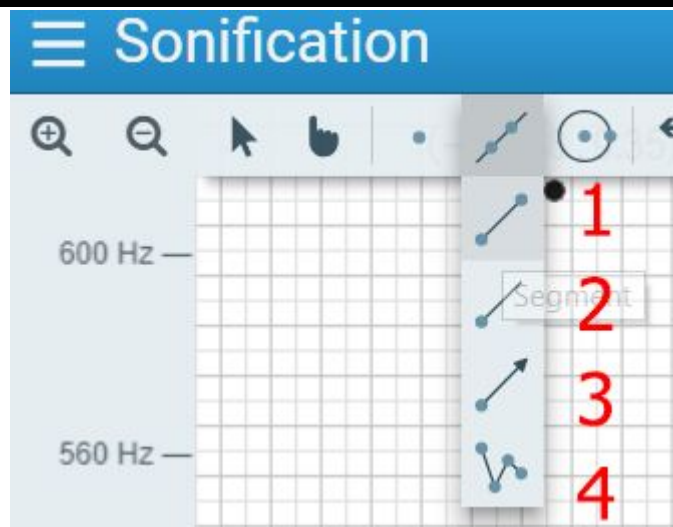


To draw a line in the coordinate system, click on 'lines' and then click on the places where you want your points.

Note: a straight line is formed by placing 2 points.

You can also opt for:

1. a line segment
2. a half-right
3. a vector
4. a polyline

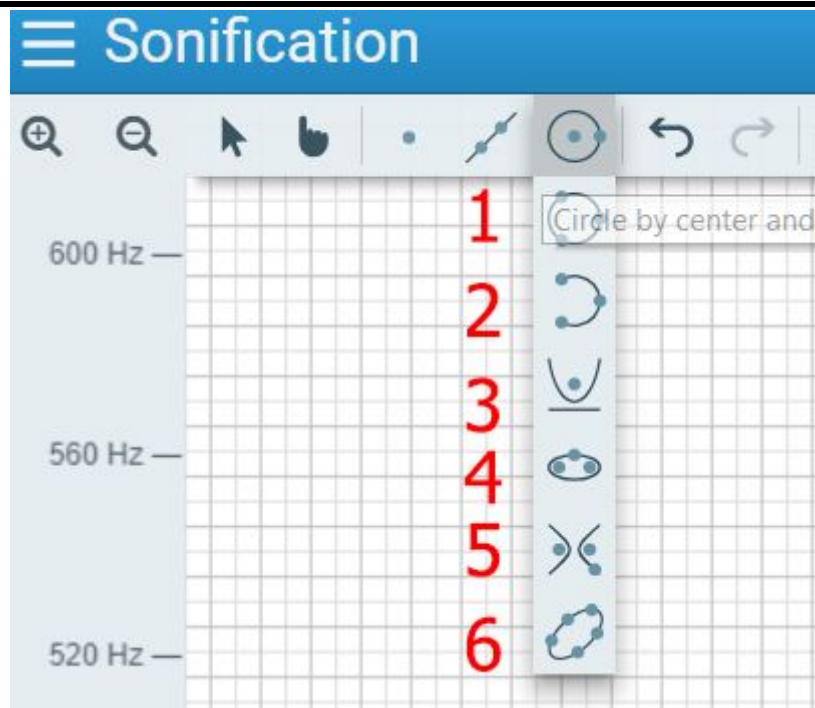


To draw a circle in the coordinate system, click on 'conical sections' and then click on the places where you want your points.

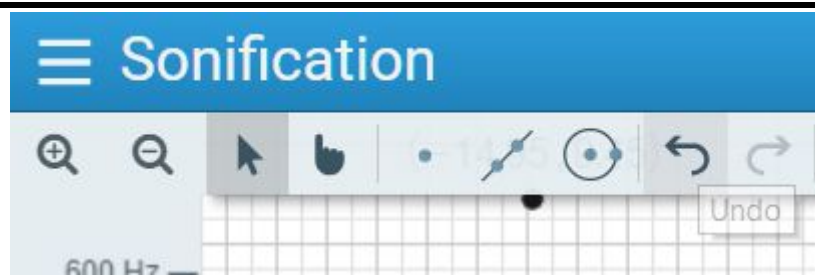
Note: a circle is formed by placing 2 points; the center and a second point to indicate the radius.

You can also opt for:

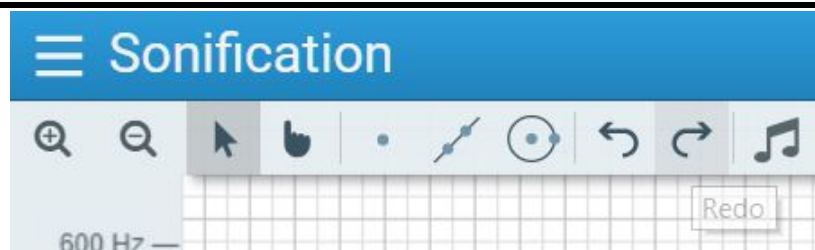
1. circle formed by three points
2. circular arc
3. parabola
4. ellipse
5. hyperbola
6. conical function

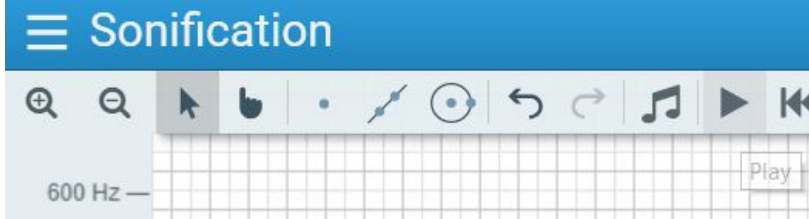
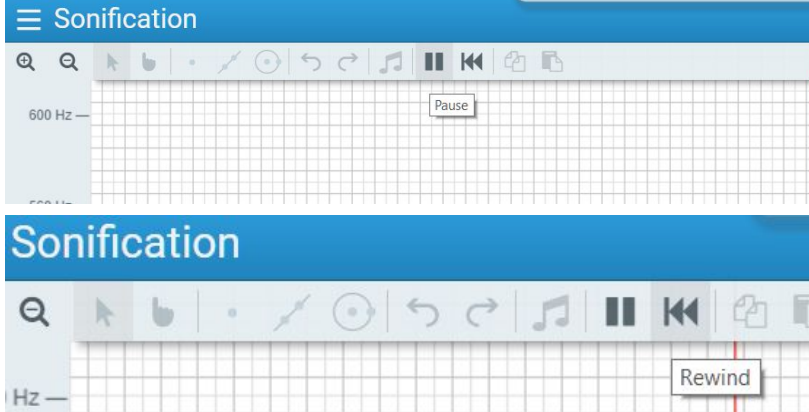
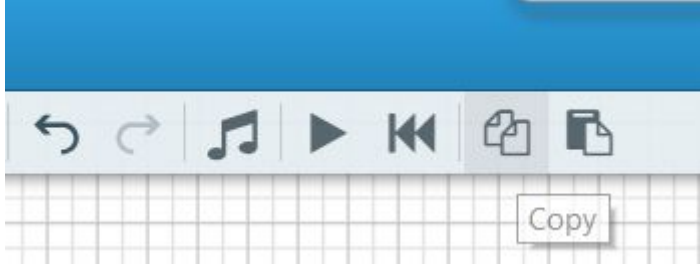
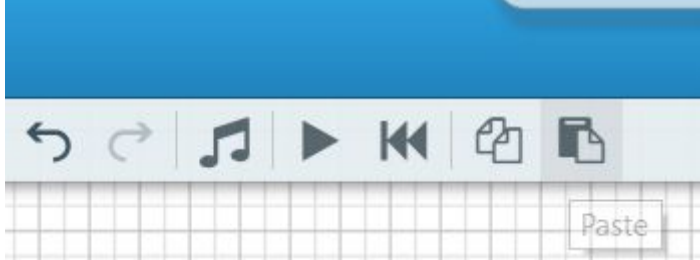
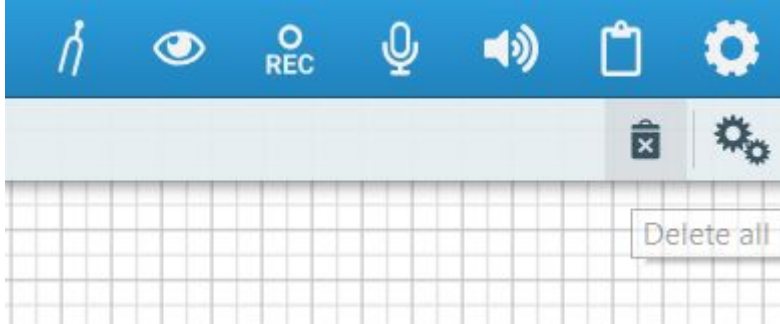


To correct a mistake, click on 'undo'.

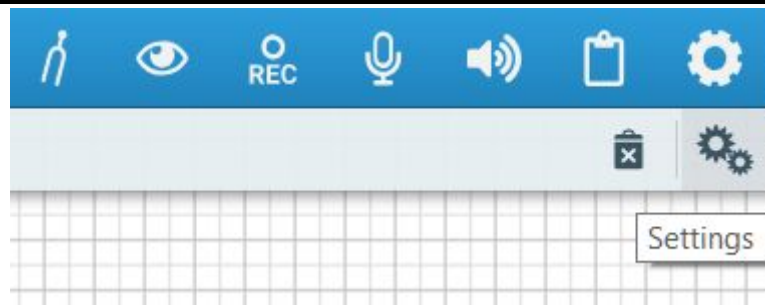


To move forward, click on 'redo'.



<p>To hear how your function sounds, you can press the 'play' button.</p>	 <p>The screenshot shows the 'Sonification' interface with a blue header. Below the header is a toolbar with various icons including zoom, pan, and a musical note icon. The 'Play' button, represented by a right-pointing triangle, is highlighted with a tooltip.</p>
<p>When you play the function, you can stop early by clicking 'pause'. To start from the beginning: click rewind</p>	 <p>The top screenshot shows the 'Pause' button (two vertical bars) highlighted with a tooltip. The bottom screenshot shows the 'Rewind' button (double left-pointing arrow) highlighted with a tooltip.</p>
<p>To copy your chart, click on 'copy'.</p>	 <p>The screenshot shows a close-up of the toolbar with the 'Copy' button (two overlapping document icons) highlighted with a tooltip.</p>
<p>To paste a function (from Handwritten Math Recognizer) so that the program automatically draws the function, click on 'paste'.</p>	 <p>The screenshot shows a close-up of the toolbar with the 'Paste' button (document icon with a plus sign) highlighted with a tooltip.</p>
<p>To clear your canvas, click on 'delete all'.</p>	 <p>The screenshot shows the bottom toolbar with the 'Delete all' button (trash can icon) highlighted with a tooltip.</p>

For additional settings you can click on 'settings'.



The following selection menu will be opened (you will get the right image by scrolling in the selection menu):

By changing the setting you can:

1. Adjust the layout of the coordinate system
2. Adjust the horizontal axis scale
3. Adjust the vertical axis scale
4. Adjust sonification

Sonification

Mode

By Frequency ▾

Instrument

Default ▾

Intensity Mode Frequency

440

Line Speed

5

Interval

220 ≤ x ≤ 2200

Step

40

Horizontal

Show axis

☒

Interval

-18.6043 ≤ x ≤ 18.6043

Label

Values

Below ▾

Axis step

1

Show grid

☒

Grid step

0.5

Subgrid divisions

2

Vertical

Show axis

☒

Interval

-10.5 ≤ y ≤ 10.5

Label

Values

Left ▾

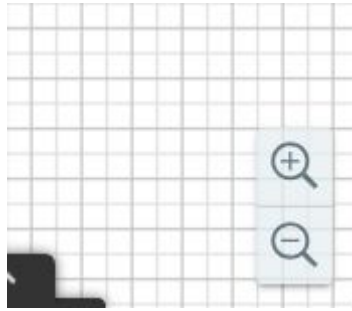
Axis step

1

Show grid

☒

To zoom in and out, click on 'zoom in' and 'zoom out' at the bottom right of the page.



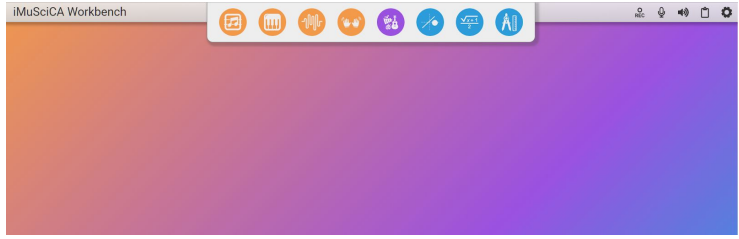
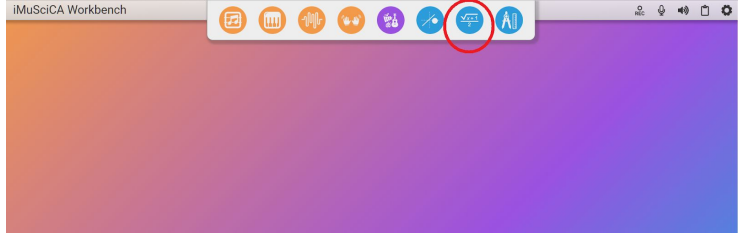
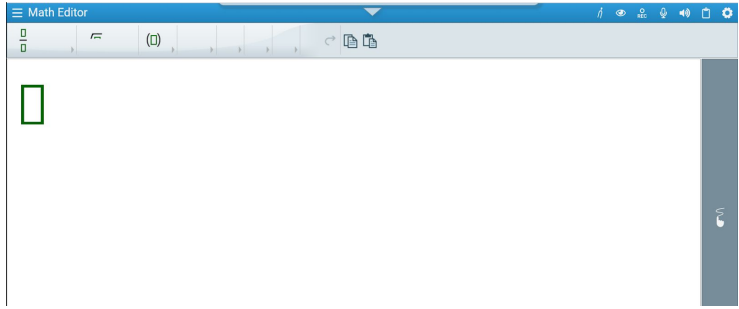
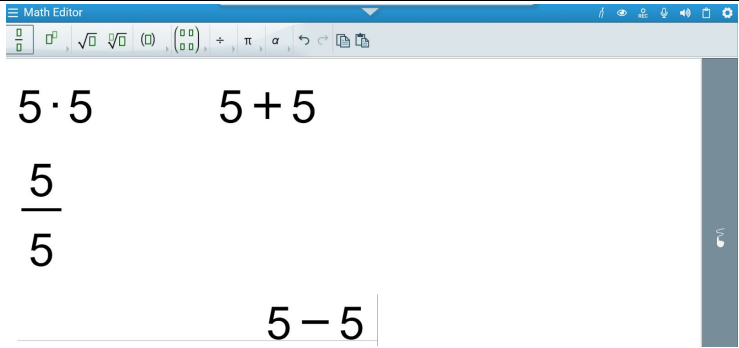

To delete a single function, first click on the 'select' button. Then click the function you want to delete. Then click on 'tt\_delete'.



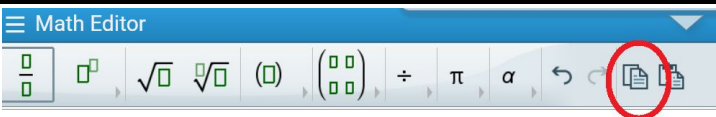
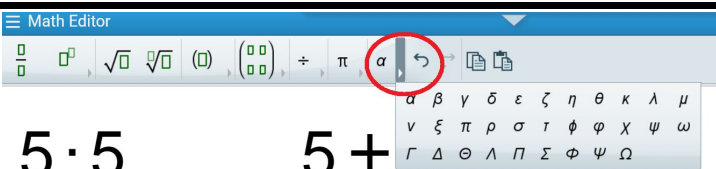
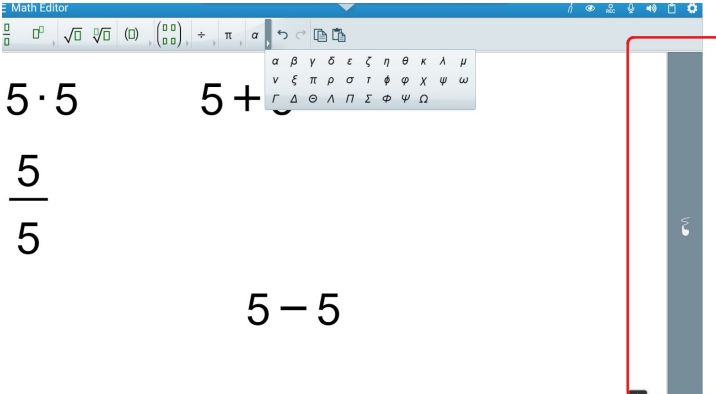
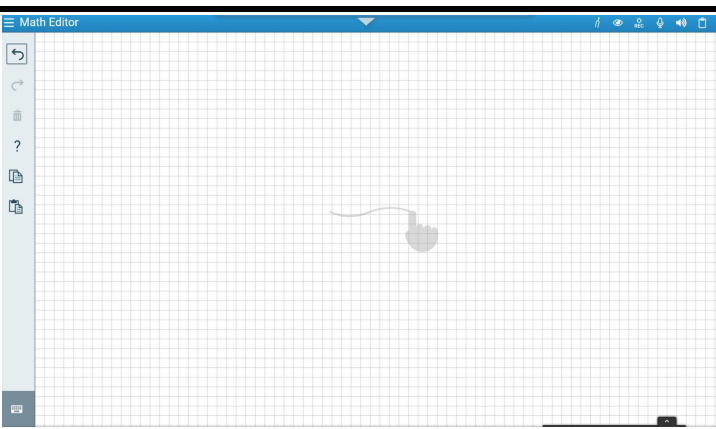
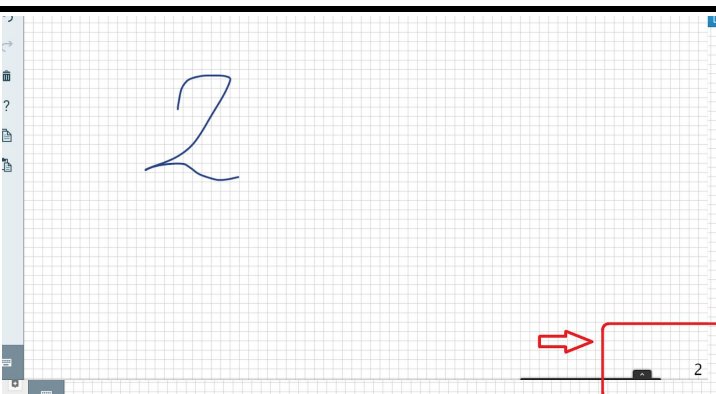
# Workbench Guide:

## Handwritten Math Recognizer

The Handwritten Math Recognizer can be used to create a function rule for a graph, which you can later insert into the Sonification tool.

<p>Open the iMuSciCA Workbench with the following link:</p> <p>workbench.imuscica.eu</p> <p>The following page will open:</p>	
<p>To open the Handwritten Math Recognizer tool, click on the blue formula.</p>	
<p>The next page appears:</p>	
<p><b>Typing formulas</b></p>	
<p>Click on the green box and enter a number and operators.</p>	
<p>On the toolbar at the top you can choose calculations by clicking on them.</p>	



<p>You can copy and paste your formula.</p>	
<p>By clicking on the arrows you can choose more options.</p>	 <p><math>5 \cdot 5</math>      <math>5 + 5</math></p>
<p><b>Writing formulas</b></p>	
<p>To switch to drawing the formulas, click on the gray bar on the right side of the screen.</p>	 <p><math>5 \cdot 5</math>      <math>5 + 5</math></p> <p><math>\frac{5}{5}</math></p> <p><math>5 - 5</math></p>
<p>The following screen will open:</p>	
<p>By writing something with your mouse (eg 2) your formula will be visible at the bottom right.</p>	

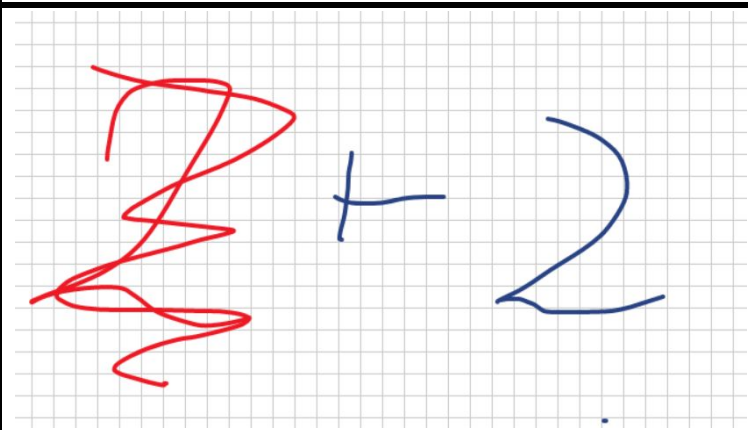


If you have drawn something wrong, you can click on the back arrow.



By scribbling in your written formula, you can delete a specific part.

For more information, click on the question mark.



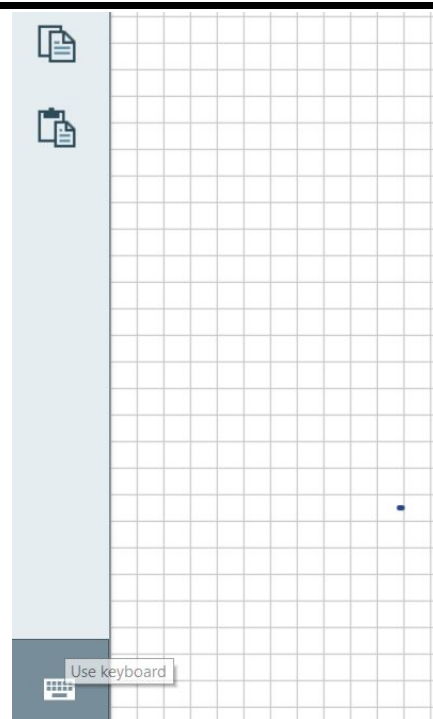
By clicking on the bin, you clear the entire canvas.



You can copy and paste your formula.



If you want to switch to typing formulas, click on the keyboard.



# Workbench Guide:

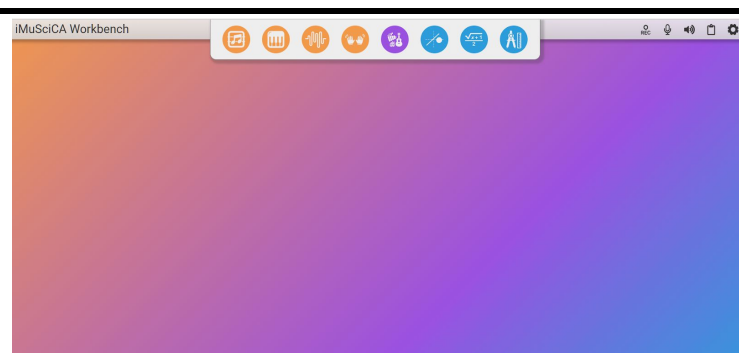
## Geometry and Algebra Tools

You can use the Geometry and Algebra Tools to provide mathematical support during the lessons. Drawings can be made, calculations can be made, transformations can be carried out and much more.

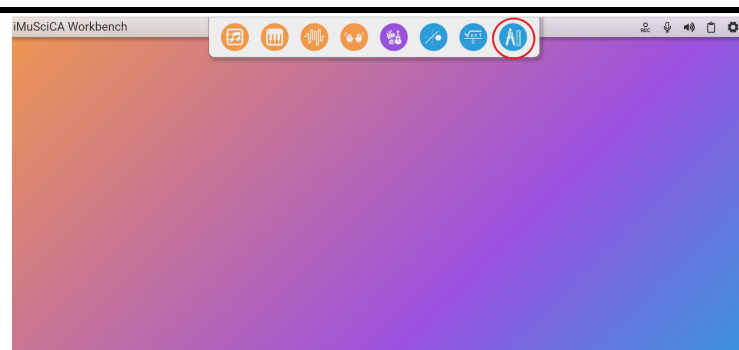
Open the iMuSciCA Workbench with the following link:

[workbench.imuscica.eu](http://workbench.imuscica.eu)

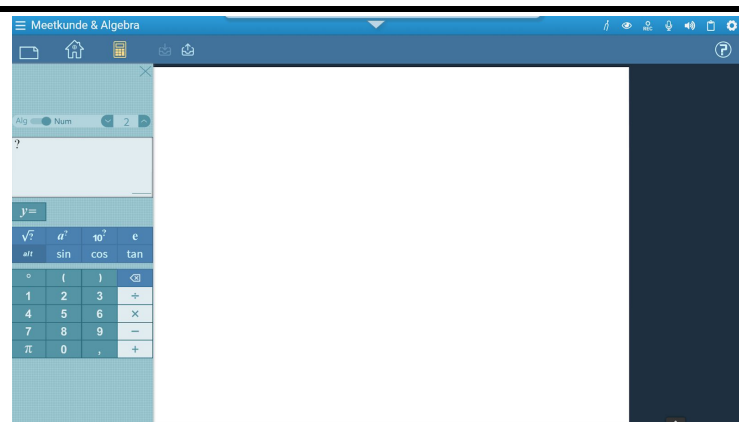
The following page will open



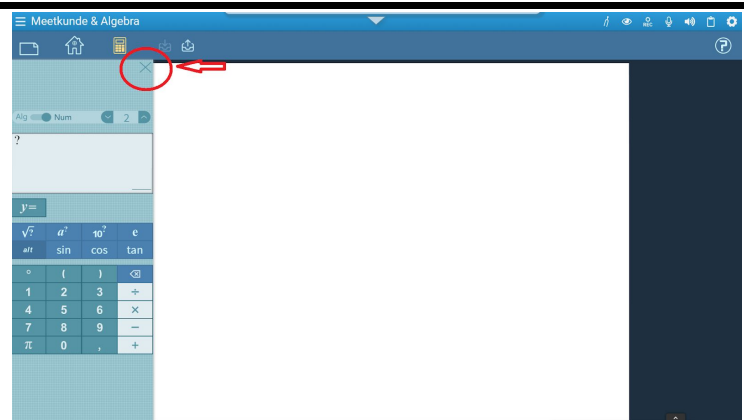
To open the Geometry and Algebra Tools tool, click on the compass and bar.



The next page appears:

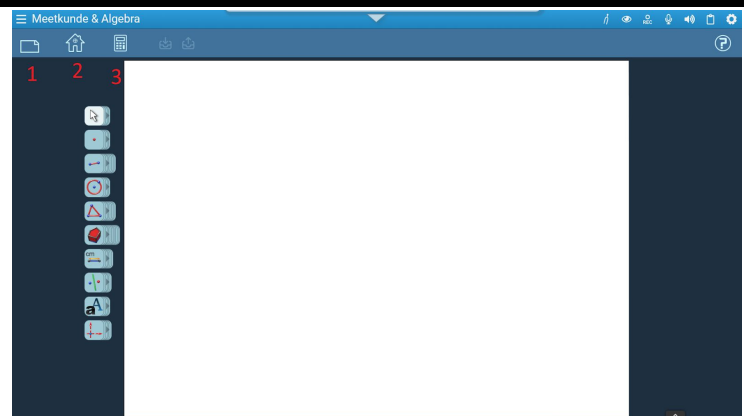


To move the calculator in the page, just grab it and drag it with the mouse. To remove it, click on the cross.

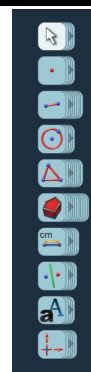


In the toolbar at the top of the canvas, you can:

1. Generate a blank sheet.
2. Put the canvas back in its original position.
3. Open / close the calculator.



By clicking on the small dark arrows in the vertical toolbar, you can choose multiple tools for constructing geometric figures in 2D and 3D or graph functions.



Discover **how geometrical symmetry operations** (like translations, reflections, rotations...) **can be performed with iMuSciCA's Geometry & Algebra tools** in following dedicated iMuSciCA's [help document](#) on symmetry operations.

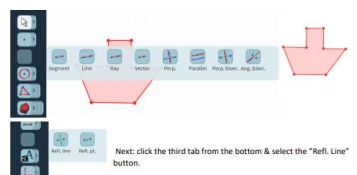
Let you be inspired by iMuSciCA's example scenario:

[Scenario 3: Synthesize the timbre of your preferred instrument](#)

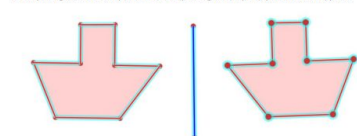
How to reflect in the iMuSciCA Geometry & Algebra tool

Open de workbench <https://workbench.imuscica.eu>

Select the icon to the right

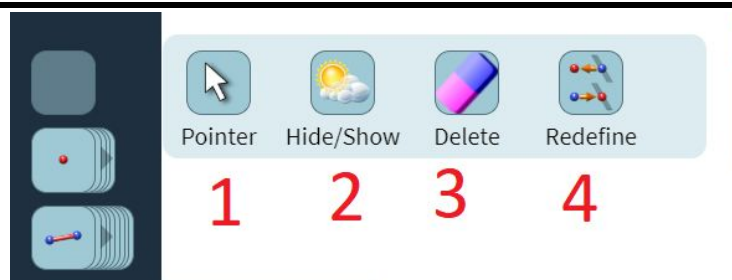


Next: click the third tab from the bottom & select the "Ref. Line" button.



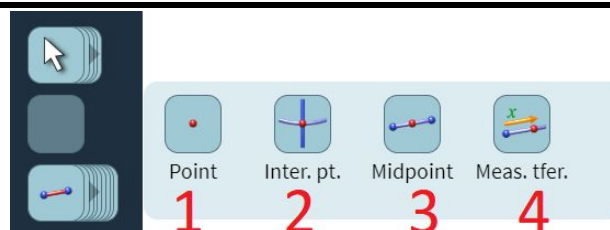
Click on the arrow on the right of the pile of the mouse pointer button and the following tools are available:

1. Take the pointer
2. Hide/show lines / figures / numbers
3. Remove lines / figures / numbers
4. Redefine a point into another one



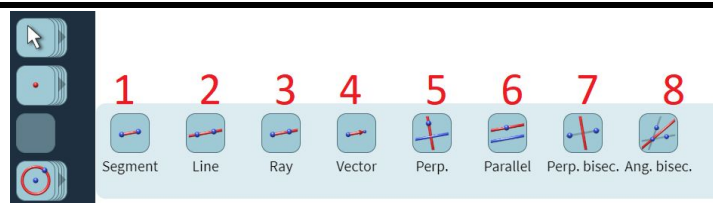
Click on the arrow on the right of the pile of the point button and following tools are available:

1. Place a point
2. Identify a crossroad of 2 lines
3. Determine the midpoint of a segment
4. Transfer a measure or a number on a segment, line, or ray.



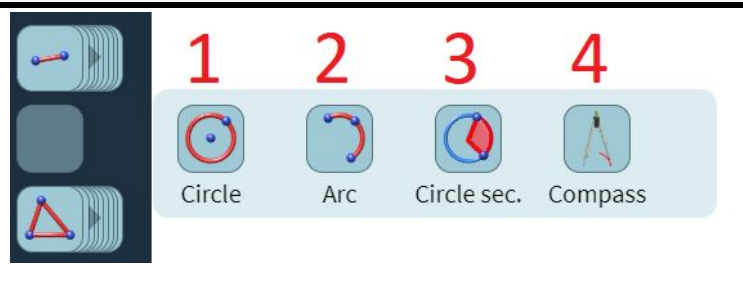
Click on the arrow on the right of the pile of the line segment button and the following tools are available:

1. Construct a segment
2. Construct a line
3. Construct a ray
4. Construct a vector
5. Construct a perpendicular line to a given line(segment, vector, ray)
6. Construct a parallel line to a line (segment, vector, ray)
7. Construct the perpendicular bisector of a line segment or of two points
8. Construct the angle bisector of an angle by clicking on one point of a side, on the angle vertex, and on a point of the other side.



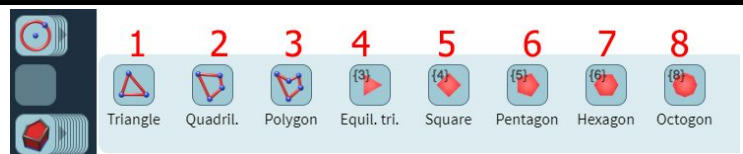
Click on the arrow on the right of the pile of the circle button and following tools are available:

1. Construct a circle
2. Construct an arc
3. Construct a circle sector
4. Construct a circle with compass



Click on the arrow on the right of the pile of the triangle button and following tools are available:

1. Construct a triangle
2. Construct a quadrilateral
3. Construct a polygon
4. Construct an equilateral triangle
5. Construct a square
6. Construct a regular pentagon
7. Construct a regular hexagon
8. Construct a regular octagon



Click on the arrow on the right of the pile of the prism button and following tools are available:

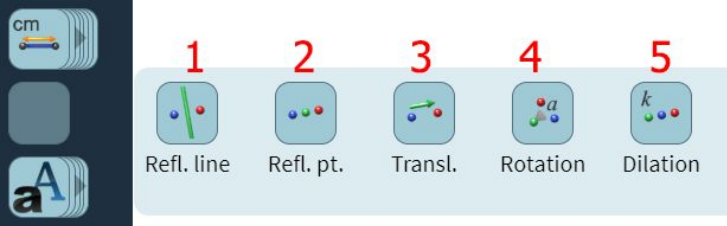
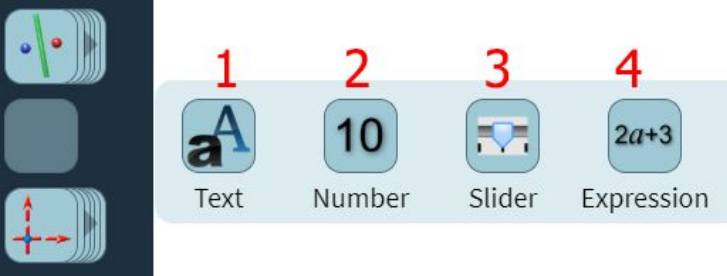

1. Construct a prism
2. Construct a pyramid
3. Construct a cylinder
4. Construct a cone
5. Construct a sphere
6. Construct a tetrahedron
7. Construct a cube
8. Construct an octahedron
9. Construct a dodecahedron
10. Construct an icosahedron
11. Obtain the foldable net from a plane net.



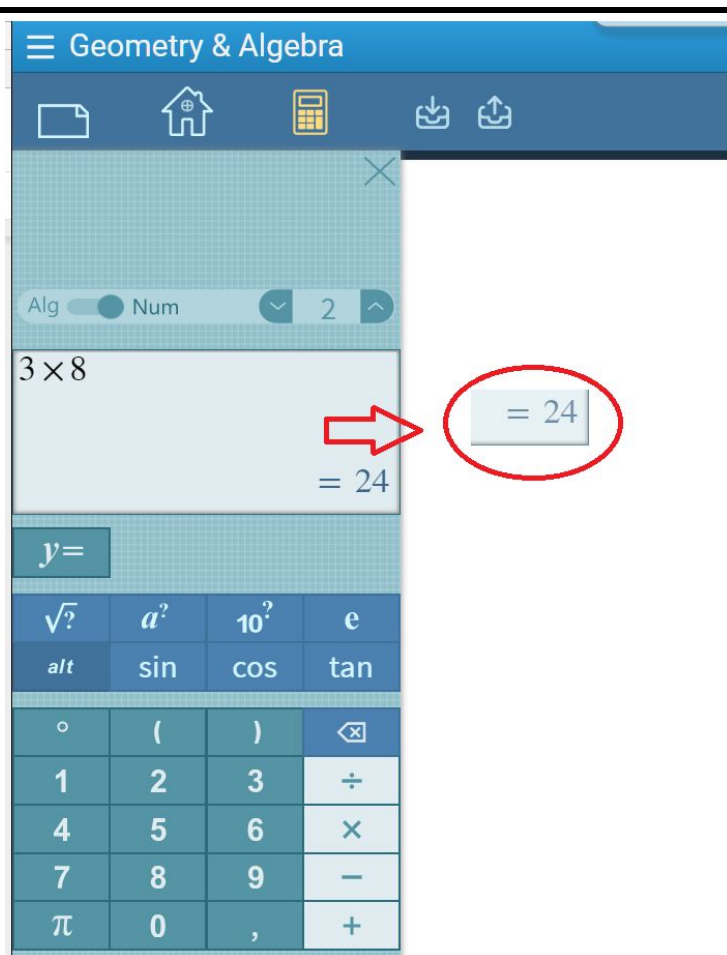
Click on the arrow on the right of the pile of the 'cm' button and the following tools are available:

1. Display the length of a segment, polygon, circle
2. Display the distance between two points
3. Display the area of a polygon or circle
4. Display the volume of a solid
5. Display the measure of an angle



<p>6. Display the coordinates of a point and the equation of a line or circle</p>	
<p>Click on the arrow on the right of the pile of the reflection button and the following tools become available:</p> <ol style="list-style-type: none"> <li>1. Reflection</li> <li>2. Reflection in a point</li> <li>3. Translation</li> <li>4. Rotation</li> <li>5. Dilation</li> </ol>	
<p>Click on the arrow on the right of the pile of the text button and the following tools are available:</p> <ol style="list-style-type: none"> <li>1. Enter text</li> <li>2. Enter a number</li> <li>3. Create a slider</li> <li>4. Enter any mathematical expression</li> </ol>	
<p>Click on the arrow on the right of the pile of the coordinate system button and the following tools become available:</p> <ol style="list-style-type: none"> <li>1. Create a coordinate system</li> <li>2. Create a grid</li> <li>3. Obtain the trace of a variable point</li> <li>4. Obtain the locus of a variable point</li> <li>5. Create the graph of a function</li> </ol>	

If you have made a calculation with your calculator, you can enter this calculation as a number in your canvas by selecting it and dragging it to the canvas.




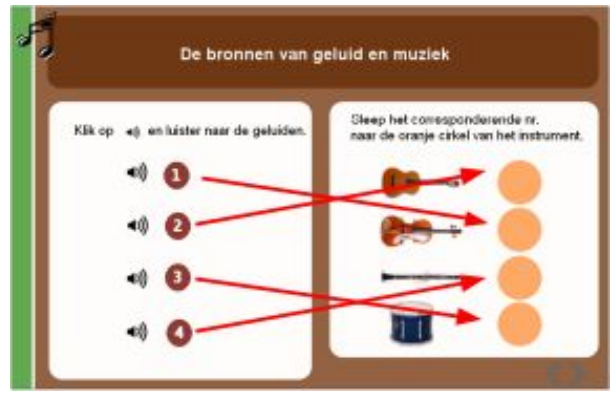
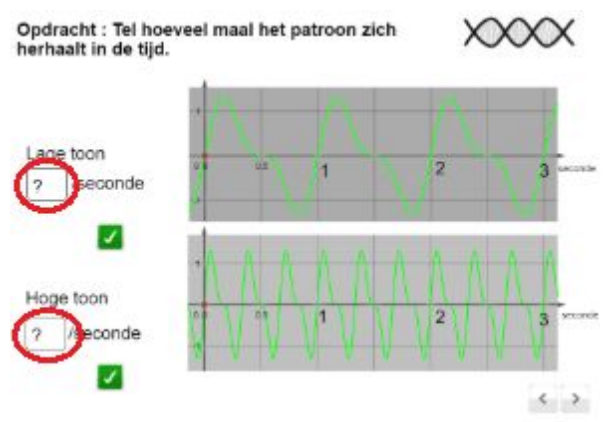
You will find more general help on Cabri at:  
<https://cabri.com/en/student/#Tutorials>  
Useful can be also (in Dutch):  
<http://users.telenet.be/tralala/eindwerk/cabrihandnopen.htm>



# Workbench Guide: Activity Books

## (Cabri Express)

Some basic scenarios (see appendix 1) are worked out as online Activity Books for students. Students can go through them themselves independently or in small working groups. They are designed to stimulate the conceptual thinking of students in interactions with the workbench tools, hand-on experiments and musical experiences. Students can open and start the online Activity Books by clicking the link in the iMuSciCA Moodle learning Environment. Moreover the links to the Activity Books are also given in appendix 1.

<p>Every Cabri starts with the front page. Press the green button to start.</p>	
<p>Solve the exercises. Drag and drop exercises and gap-exercises are being used. Drag and drop exercise: drag the number to the correct circle.</p>	
<p>gap-exercise: Enter the correct value by clicking on the place with the question mark '?'.</p>	

To listen to a specific tone or music, piece click on the speaker.

Opdracht: Luister naar de twee tonen.

Toon 1:  Toon 2: 

Welke toon is het hoogst?

- ☐ Toon 1
- ☐ Toon 2

Wat kan je zeggen over die twee tonen?

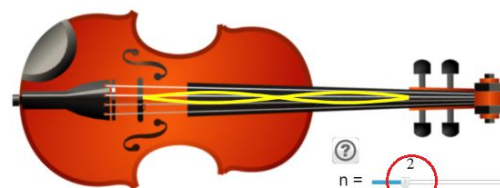
- ☐ Toon 1 klinkt lager dan toon 2.
- ☐ De twee tonen klinken hetzelfde.
- ☐ Toon 2 klinkt lager dan toon 1.



In many exercises a slider is used. To move the slider, click on the white arrow and move your mouse to the side.

Opdracht 3

Bekijk de mogelijke natuurtonen of eigenfrequenties bij een viool.




Wat gebeurt er met de golflengte van de hogere natuurtonen?

- ☐ De golflengte wordt groter.
- ☐ De golflengte wordt kleiner.
- ☐ De golflengte verandert niet.




4


To check your answer, click  A red or green circle will appear.


 : false


 : true


**De bronnen van geluid en muziek**


Klik op  en luister naar de geluiden.

 1


 2


 3


 4

Goed gedaan! 


Sleep het corresponderende nr. naar de oranje cirkel van het instrument.

 2


 1

 4

 3



To go to the next or previous page, click on the arrows at the bottom right.

Toon 1:  Toon 2: 

Welke toon is het hoogst?

- ☐ Toon 1
- ☐ Toon 2

Wat kan je zeggen over die twee tonen?

- ☐ Toon 1 klinkt lager dan toon 2.
- ☐ De twee tonen klinken hetzelfde.
- ☐ Toon 2 klinkt lager dan toon 1.

