Interactive Music Science Collaborative Activities

Team Teaching for STEAM Education

Deliverable 2.4

Intermediate Pedagogical framework and iMuSciCA use cases by learners and teachers

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Executive Summary

This deliverable describes the intermediate 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*. The basic principles of the iMuSciCA pedagogy are described in D2.1. In this deliverable we focus on the further implementation of this pedagogy within the iMuSciCA scenarios (see also deliverable *D2.3 - Initial Educational scenarios and lesson plans for iMuSciCA*) and into the iMuSciCA workbench (see also deliverable *D5.5 - Initial Demonstrators of iMuSciCA workbench toolkits*).

iMuScCA introduces a contemporary teaching methodology at the intersection between art and science, by combining the following 5 strong points:

1. iMuSciCA's innovative interdisciplinary pedagogy
2. iMuSciCA's new Inquiry Learning across STEAM fields
3. iMuSciCA's three stages: from guided towards open inquiry (like in the real STEAM-world)
4. Collaborative and co-creative learning: in different fields, each fostering the other
5. 21st century skills: across different STEAM-fields

We present in particular how this interdisciplinary pedagogy connects concepts and skills of music with those of science and engineering by involving students (and teachers) into inquiry and tinkering. STEAM-rich inquiry and tinkering activities are designed to support *interdisciplinary* investigations and creativity because they are using a STEAM-rich palette of tools, concepts, and phenomena.

The structure of the iMuSciCA pedagogical framework is so that it allows to follow a safe guided inquiry path as well give students room to more open and adventurous pathways. Therefore, iMusCiCA provides open but scaffolded paths if needed, with appropriate guiding for teachers.

In this pedagogical guide, we will explain what novelties iMuSciCA is bringing to the classroom and how iMuSciCA can help you as a teacher with this.

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Disclaimer

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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

1. Introduction

Up till now Inquiry Based Science Education (IBSE), as the name states, was mainly used in science education or at the utmost in 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 relation between concepts or skills that are being taught to them in different fields or subject matters (Honey et al., 2014). Moreover our own small curriculum study (see section 6) showed that in none of the studied countries a pedagogy connecting Music with Science and Engineering, can be found in the standard curriculum. So, iMuSciCA brings something new here.

> Example: Students in school learn about waves and superposition in physics and mathematics, they don't connect this to what they are experiencing in music: melody, timbre or harmony. The same goes for engineering: while designing their own instrument, supposed they will get a task like this in standard curriculum (but it is one of the iMuSciCA scenarios!) they hardly experience that concepts of maths and physics are at stake there.

iMuscica on the other hand really focuses on these intertwinings and this on many dimensions: interdisciplinary concepts and skills (see section 2.1), inquiries across fields (see section 2.2), stages from guided to unguided (see section 2.3), collaborative and co-creative learning (Section 2.4) and 21st century skills (section 2.5)

In section 3, you discover what makes up the iMuSciCA Learning environment. It goes from a workbench where you can find different tools, over pedagogical guided scenarios to see how iMuSciCA will really work in your classroom towards ready to go template scenarios made in the Cabri Express environment who will start a mouse-click away.

In section 4, you 'll find out how the interdisciplinary nature of iMuSciCA can be found back on the iMuSciCA workbench, in the inquiry scenarios, in the content, in the connected concepts, in the tinkering, in the different manners of inquiry (inquiry in music is not the same as in engineering!), in the way students are led from guided to more open forms of inquiry, in the shared active experiences of teaching and learning (shared among students working in small groups, but also shared between teachers of different disciplines), in encouraging learning transfer and fostering creativity between and across different STEAM disciplines.

In sections 5, you will find an example of an iMuSciCA scenario you can deploy in your classroom. It is about 'designing your own instrument playing natural tones'. It will be explained how your students can follow a more safe pathway of guided inquiry or maybe you prefer a more open adventurous approach and start directly by playing with one of the iMuSciCA tools. More pedagogical scenarios are provided in deliverable *D2.3 - Initial Educational scenarios and lesson plans for iMuSciCA*.

In section 6, it is showed, albeit an intertwined STEAM pedagogy is mostly not part of standard curriculum, you can discover how you can connect it to your curriculum anyway by combining learning goals of different subject matter fields.

These interdisciplinary pedagogical methodologies and the combination of them all in iMuSciCA is quite unique. With the use of state of the art educational technology tools, developed by the iMuSciCA consortium, we hope to develop this innovative interdisciplinary pedagogy further. In three countries there is an intensive piloting and collaboration with teachers in schools. The experiences in school are collected and iMuSciCA is continuously improved on this and other feedback. This way iMuSciCA hopes to give active, discovery-based, and more engaging learning, with opportunities for collaboration, co-creation and collective knowledge building.

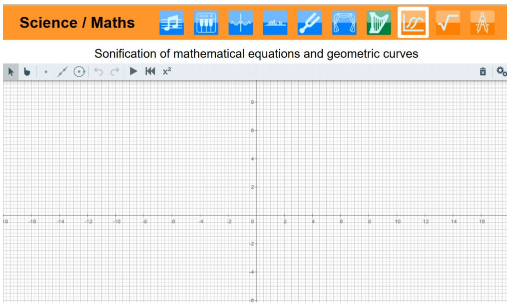


Figure 1. The iMuSciCA workbench with the Sonification of Maths equations opened: one of the tools students can play with on the iMuSciCA workbench

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

We explain in this section how iMuScCA 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 three stages: from guided towards open inquiry** (like in real STEAM-world)
4. **Collaborative and co-creative learning**: in different fields, each fostering the other.
5. **21st century skills**: across different STEAM-fields.

While in this section we give the background and rationale of iMuSciCA's pedagogy around these 5 strong points, we will give in section 5 'typical iMuSciCA use case scenario' a concrete example of an innovative iMuSciCA scenario and how these 5 points do land in a lesson or scenario. Hence, this section is about the what and the why. Section 5 is about the how it's done.

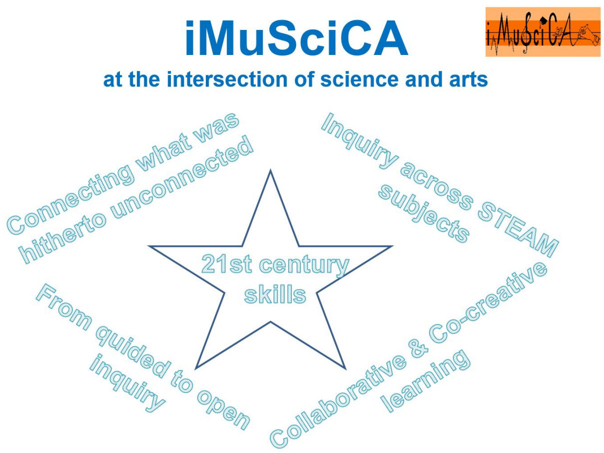


Figure 2. Innovative features of iMuSciCA's pedagogy

2.1. iMuSciCA's innovative, interdisciplinary Pedagogy

STEM education initiatives need to build in opportunities

that **make STEM connections explicit to students and educators**

(Honey et al., 2014)

To connect what was hitherto unconnected in education

At the heart of the iMuSciCA pedagogy is the idea that **concepts of different fields, mostly left unconnected in schools, are now seen in relation to each other**. Most students nowadays in school see hardly ever relation between concepts that are being taught to them in different fields or subject matters (Honey et al., 2014). Moreover our own small curriculum study (see section 6) showed that in none of the studied countries a pedagogy connecting Music with Science and Engineering, can be found in the standard curriculum. So, iMuSciCA brings something new here.

One of the strong points of iMuSciCA's new pedagogy is to foster these connections and to make them explicit to learners, by making them experience and discover relations between hitherto unrelated subject matters. iMuSciCA provides to schools tools and lesson scenarios that will bring this connecting STEAM pedagogy to classes.

iMuSciCA let students experience a 'many worlds' journey through these different STEAM fields and let them learn how inquiries in those worlds differ, but are related at the same time.

Below under section *5. and also in appendix 1,* you will find an example scenario. We will illustrate there how iMuSciCA connects hitherto in schools unrelated fields in an intertwined pedagogy. The final goal of this example scenario is *to design an own musical instrument based on the natural tones*.

Typically a scenario gives a general framework for the treated concepts, like for example the sample scenario we describe under section *5*: it is about creating and playing an own instrument, which is the final goal of the scenario. So pupils are motivated to move forward and learn about the treated concepts while looking for the realization of this goal. The concepts used in each lesson of a scenario are schematically summarized at the end of each lesson plan, so to make them explicit also to the learner.

Tinkering in an interdisciplinary context: design, make, play

But there is more: iMuSciCA's interdisciplinary STEAM give a ideal milieu for **tinkering** too. Tinkering as a branch of making that emphasizes creative, improvisational problem solving. STEM-rich tinkering activities are designed to support *interdisciplinary* investigations and creativity using a STEM-rich palette of tools, concepts, and phenomena. [Honey & Kanter, 2013 ; Martinez & Stager, 2013]

In many scenarios and inquiries of iMuSciCA students are involved in typical interdisciplinary tinkering tasks like 'built your own bottle organ' or 'make your own flute'. These are tinkering challenges where a lot of collaborative skills and insights are requested. **Design, make, play: it is all in iMuSciCA's pedagogy** in order to grow the next generation of STEM innovators [Honey & Kanter, 2013].

2.2. iMuSciCA's new Inquiry Learning across STEAM fields

Up till now Inquiry Based Science Education (IBSE), as the name states, was mainly used in science itself or in other fields too like music or engineering at the utmost, but if then as separated inquiries in each subject matter field (see for instance Pedaste et al., 2015).

iMuSciCA now brings inquiry learning into classroom but across disciplines ***in a connected way***. iMuSciCA's brings IBSE in a crosscutting threefold way:

1. Stage 1: **IBSE pedagogy in science education**
2. Stage 2: IBSE pedagogy **in different fields**: Music, Science & Engineering
3. Stage 3: show how IBSE in different fields **is connected**

The IBSE phases are maye quite classic but **iMuSciCA uses them across the different STEAM fields**:

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

As indicated in the iMuSciCA STEAM-pedagogy, these phases are made explicit in the iMuSciCA scenarios and lessons, both to the teachers and to the pupils. 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 reflects also the sometimes quite dazzling inquiry paths that occur in the real STEAM world.

iMuSciCA uses these different IBSE phases in the different STEAM fields *on a connected way. That* is new to schools who were used to do IBSE up till now mainly in science. 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 as to let room to activities usually not incorporated in science inquiry.**

<u>**Example**</u> **"Creation" phase** in the iMuSciCA scenario **Design your instrument.** We show here how iMuSciCA *broadens and connects* traditional <u>inquiry phases across disciplines</u>.

Creation <u>*in Music*</u>

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.

Creation <u>*in Science-Mathematics*</u>

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.

Creation <u>in *Technology-Engineering*</u>

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.

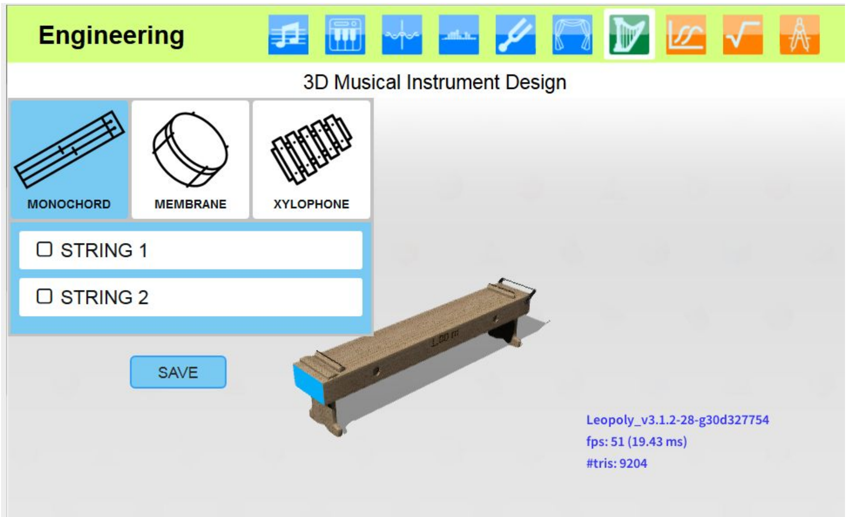


Figure 3. The iMuSciCA workbench with the 3D musical instrument design opened

You will find more details on how iMuSciCA's innovative IBSE pedagogy works across these fields in every IBSE-phase in Appendix 2.

2.3. iMuSciCA's three stages: from guided to open inquiry (like in real STEAM-world)

iMuSciCA adopts a STEAM inquiry phases model which reflects the ideas of Deeper Learning (http://www.hewlett.org/strategy/deeper-learning/), which is applicable to the world of music (A), technology-engineering (T-E) and science-mathematics (S-M).

The inquiry phases are used as a model, so there are not meant to be followed always in a fixed sequence: one starts most of the time in a sort of engaging phase, many times in the field of music, but also scientific or engineering questions (e.g. design your own instrument)can be very engaging. The logical path after such an engaging phase would be typical following sequence: imagine, create, analyse, communicate (for more details on the inquiry phases see appendix 2). But other paths are also possible, for instance some where some phases come back and back again before proceeding towards the more final 'communicate and reflect' phase.

The iMuSciCA pedagogy introduces also a more **innovative approach towards** the **inquiry** phases too, because in many inquiry projects there are applied as a too strict and almost frightening framework which is far from the reality of inquiry in research institutions and companies (namely, the real STEM world). The iMuSciCA pedagogy wants to reflect more genuinely the research in the real world where:

1. Different disciplines are connected
2. Inquiry is done in different disciplines
3. Inquiry phases follow many times a more adventurous pathway than the model sequence from phase A to Z.

In this sense, iMuSciCA brings a more open and genuine inquiry to the school, one you will more likely find in the real STEAM world. The iMuSciCA scenarios, lesson plans, as well as the structure of the iMuSciCA workbench, reflects this open and diverse pedagogy. Indeed iMuSciCA offers teachers and students two connected ways into the STEAM world: a path from more guided towards more open inquiry. By providing students with necessary background knowledge on demand, iMuSciCA's pedagogy avoids recent reported pitfalls for those methods of inquiry who go too quickly to the most open form: these turn out to be quite negative for students of less privileged background. The advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide "internal" guidance. (Kirschner et al., 2006)

Therefore, iMuSciCA provides **three stages in using its inquiry STEAM pedagogy**; from guided inquiry over open but scaffolded inquiry towards free inquiry.

1. *Stage 1: Guided Inquiry as a introduction to inquiry learning across fields*

Students learn to perform activities in which the needed concepts are introduced in a logical order. In this case the innovative character of the pedagogy lies in the connected way they learn to apply the inquiry phases in different fields like music, science and engineering. They learn to see connections between concepts across different disciplines, hitherto belonging to "separate worlds".

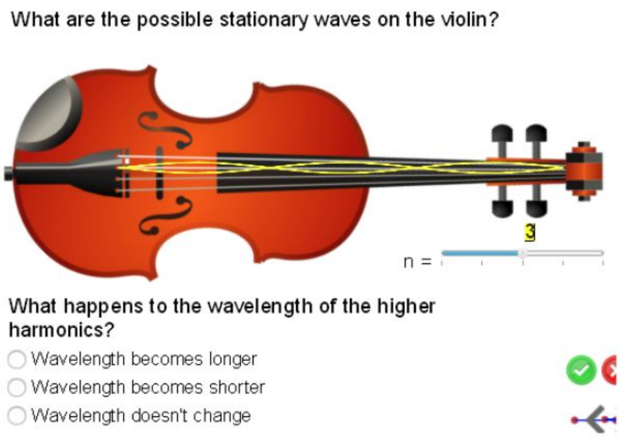


Figure 4. An iMuSciCA template lesson where students are asked to inquire stationary waves on a violin with the use of a Cabri animation

2. *Stage 2: iMuSciCA's* open inquiry scenarios

Some iMuSciCA scenarios are quite open and set goals like "design your instrument". In order to reach this goal you can use the workbench tools (like the iMuSciCA 3D musical instrument design activity environment) as they are and walk through some other scenarios as well. In fact you can go 'your own way' through some of them as building blocks in order to reach your goal: building your own instrument. So iMuSciCA provides you with the necessary background in your open inquiries. This scaffolding in open inquiry is quite necessary as is reported by (Kirschner, 2006). iMuSciCA provides just that and so it can claim open inquiry possibilities for all. The iMuSciCA workbench tools and template **scenarios can offer a framework through which teachers and students can freely move but get some scaffolding when needed**: iMuSciCA supports the learning whenever needed, in order to reach the principal goal set out by open inquiries. One can chose in which order and whether to do all lesson plans or not. So it is more a path of **knowledge on demand**.

3. Stage 3: free use of the iMuSciCA workbench

The tools in the iMuSciCA workbench can also be also used in a completely free manner by teachers or students. **Teacher can then create their own lesson plans based on the use *of* the tools in the workbench**, **or pupils are let free to perform activities using these tools**. The prewritten scenarios can serve as a source of inspiration.

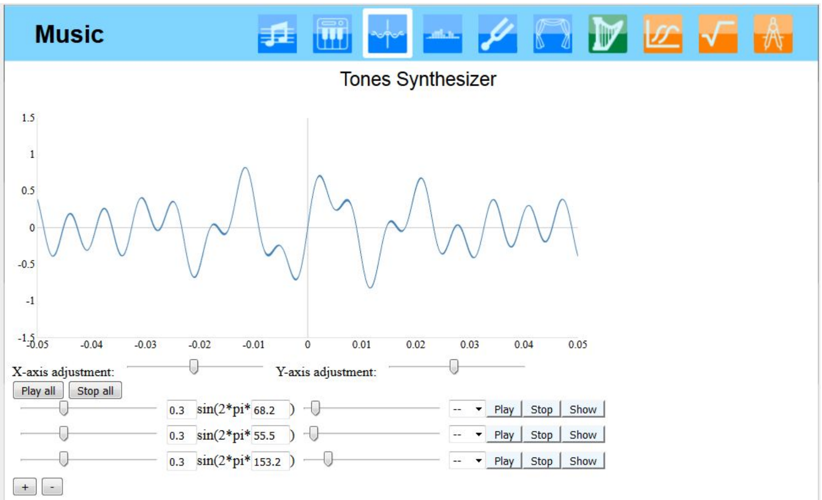
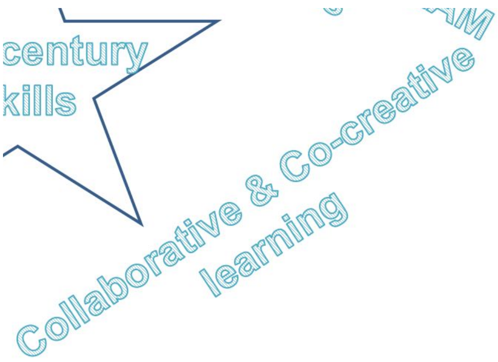


Figure 5. Playing with the iMuSciCA Tone Synthesizer

The proposed STEAM pedagogy wants to make a link with the real STEAM world outside the classroom. In this sense the STEAM Pedagogy in the classroom reflects the STEAM world out there. 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).

2.4. Collaborative and co-creative learning

Many (if not all) of the iMuSciCA activities are designed to meet the following requirements for collaborative learning (Kischner, 2001):



#1. Active learning: iMuSciCA is built around scenarios that engages students from different perspectives: music, science, engineering. Moreover, scenarios are designed around inquiries that actively involves the students both in thinking as in designing. iMuscica involves a lot of **tinkering** as well like e.g. built your own instrument. STEM-rich tinkering activities are designed to support *interdisciplinary* investigations and creativity (See Section 2, Honey & Kanter, 2013 ; Martinez & Stager, 2013). In these are tinkering challenges a lot of collaborative skills and insights are requested.

#2. Teacher is usually more a **facilitator**: the role of the teacher in iMuSciCA is to support the learning by intervening when needed. But also to create time at the right moments for making conclusions about the learned concepts and for discussions between the different groups. Still some guidance might be needed, especially for those with weak or less privileged background; Teachers can recommend different pathways through the different iMuSciCA scenarios depending on student's background.

#3. Teaching and **learning** are **shared experiences**: both within student groups (different roles for students from a content point of view are possible in iMuSciCA, so *interdisciplinary teams*) and shared as well between students and the teachers. In case of iMuSciCA teachers we talk about them *in plural*, since iMuSciCA recommends to involve **teachers of different background** into the project (for instance science and music teachers).

#4. Students participate in **small-group activities**: learn to collaborate with peers and to share their own ideas about the studied subjects in the different STEAM-fields.

#5. Students must take **responsibility for learning**: In taking responsibility it could be done in some of the proposed activities to put together pupils with different responsibilities based on their 'preferences', like for example:

> Example: a pupil which already is acquainted with music could help others during the simple music performance activities (see suggestions in the pedagogical guide section in appendix 1); or a pupil which is more used in making something with its hands could contribute more in the engineering activities; and so on.

#6. Students are stimulated to **reflect** on their own **assumptions** and **thought processes**: the iMuSciCA pedagogy and inquiry phases foresees explicit 'Communicate and reflect' phases where the time is halted to see 'where we are' and during which social and team skills are further developed.

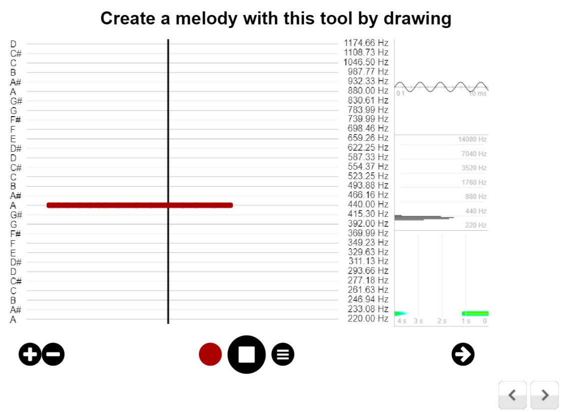


Figure 6. Students can create their own melody (for their phone?) using the iMuSciCA workbench, but now they can measure the frequencies and the spectrum too

In this way, the iMuSciCA pedagogy **teaches students how to collaborate** with others and this reflects again the real STEM-STEAM world, where scientists, engineers, technicians, mathematicians and in some cases artists work together to reach their results.

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 as an innovative practice could give some input on this research as well. For more details see also 3.2 Structure of scenarios, lesson plans and activities.

2.5. 21st century skills

The relevance of a specific topic is clearer to students
when they understand how it fits within the big picture.

[Saavedra & Opfer, 2012]

Various learning scientists came to the insight that a contemporary pedagogy needs to addresses 21st century skills. [Wagner, 2008] for instance, proposes that students need seven ‘survival skills’ in the 21st century including:

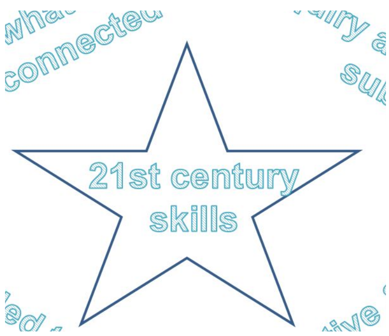
1. Critical thinking and problem solving
2. Collaboration and leadership
3. Agility and adaptability
4. Initiative and entrepreneurialism
5. Effective oral and written communication
6. Accessing and analyzing information
7. Curiosity and imagination.

Many of the proposed skills are related to transfer, metacognition, teamwork, technology, and creativity… and iMuSciCA’s pedagogy has in itself these characteristics. So iMuSciCA’s pedagogy reflects precisely the 21st century skills the pedagogy is aiming. At the same time these skills are also characteristics of the pedagogy itself.

[Saavedra & Opfer, 2012] distinguish following ‘9 lessons’ *for a pedagogy that addresses 21st-century learning*:

#1. Make it relevant.
#2. Teach through the disciplines.
#3. Develop thinking skills.
#4. Encourage learning transfer.
#5. Teach students how to learn.
#6. Address misunderstandings directly.
#7. Treat teamwork like an outcome.
#8. Exploit technology to support learning.
#9. Foster creativity.

Source: [Saavedra & Opfer, 2012]



These 9 pedagogical recommendations are taken into account into the iMuSciCA pedagogy. We will demonstrate below how each of these 21st century characteristics are addressed.

#1. Make it relevant. To be effective, curriculum must be relevant to students. iMuSciCA begins with generative topics at the intersection of music, science and engineering. Those topics have an important place in the disciplinary or interdisciplinary framework. Evidently the **context of music iMuSciCA 'resonates' with learners and teachers** (Perkins, 2010).

#2. Teach through the disciplines. In a classical model of education, teachers transmit factual knowledge to students via lectures and textbooks, which are bound to a certain subject matter like mathematics, physics, music, engineering. This remains the dominant approach to compulsory education in much of the world [OECD, 2009]. Typically students taught in this way, don't have much practice applying their knowledge to new contexts, solve new problems, or using it as a platform to develop creativity. The iMuSciCA pedagogy overcomes exactly these pitfalls by connecting disciplines, to make theoretical knowledge transferable and applicable throughout different disciplines and contexts.

#3. Develop thinking skills. Students in iMuSciCA can develop lower- and higher-order thinking skills simultaneously. For example, students practice lower-order skills by plugging numbers into an equation or a table as a way to understand the relationship between frequency and natural tones. To deepen understanding of that relationship, iMuSciCA foresees questions that require higher-order thinking to answer, such as "Why is there such a clear relationship between the frequencies of natural tones? How will instruments work than if they are be played with natural tones?" Addressing these questions successfully, while more difficult, contributes to flexible and applicable understanding and that is exactly what students need to do to successfully negotiate the demands of the 21st century [Schwartz & Fischer, 2006]

#4. Encourage learning transfer. Students in iMuSciCA can **apply** the **skills and knowledge they gain in one discipline to another** and what they learn in school **to other** areas **of their lives** [Fogarty, Perkins & Barell, 1992]. Ordinary instruction doesn't prepare learners well to transfer what they learn, but explicit attention to the challenges of transfer can cultivate it. However, transfer is hard and students need support and practice to ensure that it happens. By connecting different disciplines in the appealing context of music, iMuSciCA powerfully supports transfer. Questions are asked to make conceptual connections between scientific laws and real-life situations [Salomon & Perkins, 1989]. The same goes for the other fields music and engineering. iMuSciCA especially addresses skills, concepts, knowledge, attitudes, and/or strategies in this transfer:

i. from different fields
ii. apply them in other fields and towards daily life mostly in the context of music.

#5. Teach students how to learn. The collaborative and inquiry iMuSciCA pedagogy develops students' metacognition by encouraging them to explicitly examine how they think. At certain times in the iMuSciCA template lessons, learning time is interrupted in order to ask students to step back and asked what they found and how they did that. iMuSciCA supports students' development of positive mental models: students benefit from believing that intelligence and capacity increase with effort and that mistakes and failures are opportunities for growth rather than the opposite [Dweck, 2000]. iMuSciCA reinforces students' metacognition by addressing reflection on a regular basis, talking through their own thinking as they address an example problem or reflect on their model or present their scheme to peers.

Figure 7. In iMuSciCA students learn to apply skills they gain in one discipline to another; their collaborative and inquiry activities reflects in classroom the real world of STEAM

#6. Address misunderstandings directly. Learners have many misunderstandings about how the world really works, and they hold onto misconceptions until they have the opportunity to build alternative explanations based on experience [Perkins & Grotzer, 2008]. iMuSciCA's pedagogy confronts student's 'theory' every time again with practice and evidence both from real life (music as they know it) as in the fields of science, engineering and music as a field in itself.

#7. Treat teamwork like an outcome. The ability to collaborate with others is an important 21st-century skill and an important condition for optimal learning. People should learn to 'play' from and with their peers and the coach. iMuSciCA is precisely combining this collaborative learning with peers on an inquiry manner. The role of the teacher is more like that of a guide or mentor rather than being someone who is just passing on knowledge.
iMuSciCA's methodology let students discuss concepts in pairs or groups and share what they understand with the rest of the class. They can develop arguments and debate them. iMuSciCA is about some kind of a *a studio format* in which several students work through a given issue, talking through their thinking process.

#8. Exploit technology to support learning. Technology offers the potential to develop students' 21st-century skills by providing them with new ways to develop their problem solving, critical thinking, and communication skills. The **iMuSciCA workbench** creates a virtual experiencing environment where virtual instruments can be tested or designed, experiments can be performed and by doing so, this helps students practice transferring skills and knowledge to different contexts, reflect on their thinking and that of their peers, practice addressing their misunderstandings, and collaborate with peers.

#9. Foster creativity. Like intelligence and learning capacity, creativity is not a fixed characteristic that people either have or do not have. Rather, it is incremental, such that students can learn to be more creative. **Creative development requires structure and intentionality from teachers and students and can be learned through the disciplines** [Robinson, 2001]. iMuSciCA across disciplines makes lessons relevant to their lives, and more intrinsically motivated students learn and use newfound knowledge more what fosters creativity [Csikszentmihalyi, 2008; Sternberg, 2006] Identifying creativity can help students recognize their own creative capacities when they might not otherwise. iMuSciCA directly addresses this creative process across different fields and this animates creative development.

3. The iMuSciCA Learning Environment

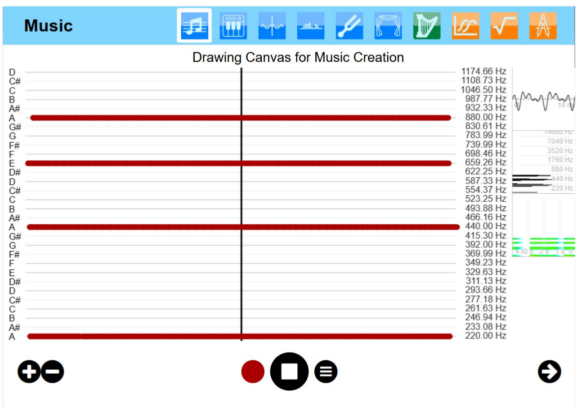
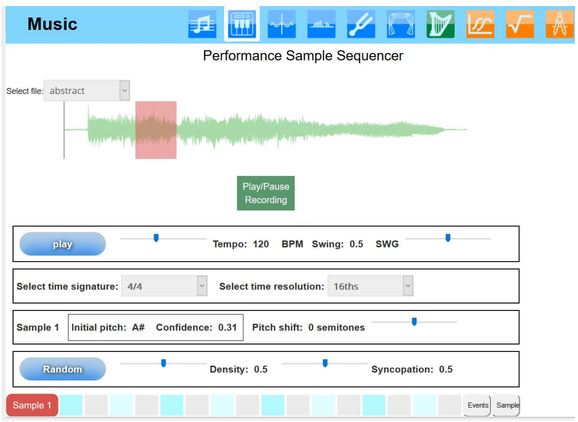
iMuSciCA creates a learning environment that consists out of four main realisations that can be used by teachers and students:

1. The iMuSciCA workbench
2. The iMuSciCA pedagogical guide that describes different iMuSciCA scenarios
3. The iMuSciCA Learning Management System
4. The iMuSciCA scenarios implemented on the Cabri Express: Ready to go

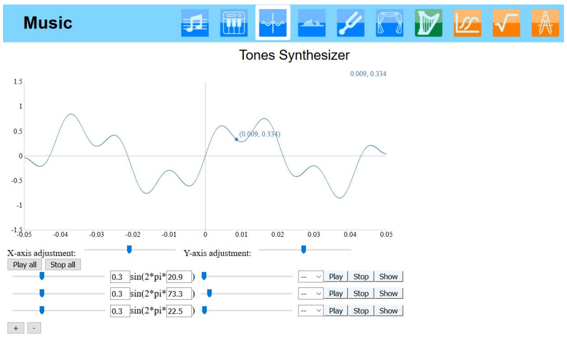
We will describe each of the above iMuSciCA realisations in this section. All together they form the learning environment iMuSciCA created for the students and their teachers.

3.1. The iMuSciCA workbench

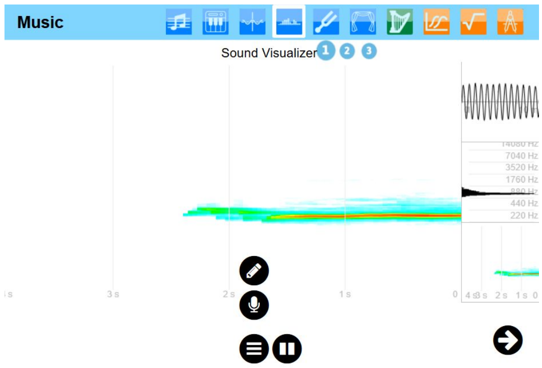
On the iMuSciCA workbench you'll find tools that let you experiment within the three different fields of iMuSciCA: Music, Science/Maths and Technology/Engineering. We list here the tools that are presently on iMuSciCA's workbench (status 20/12/2017). More background on the tools themselves and on the iMuSciCA workbench can be found in D5.5 - Initial Demonstrators of iMuSciCA workbench toolkits. More on how iMuSciCA's pedagogy is realised with the use of the total iMuSciCA Learning Environment can be found in section 5 where we give a typical example of a use case scenario. Of course the different pedagogical scenario guides that iMuSciCA has developed and is still developing, give more concrete view on what will happen in the classroom when teachers will work with iMuSciCA (see appendix 1 for an example of a pedagogical scenario guide, or see D2.3 - Initial Educational scenarios and lesson plans for iMuSciCA for more scenarios or lesson plans).

Drawing Canvas for Music Creation	**Performance Sampler Sequencer**
	

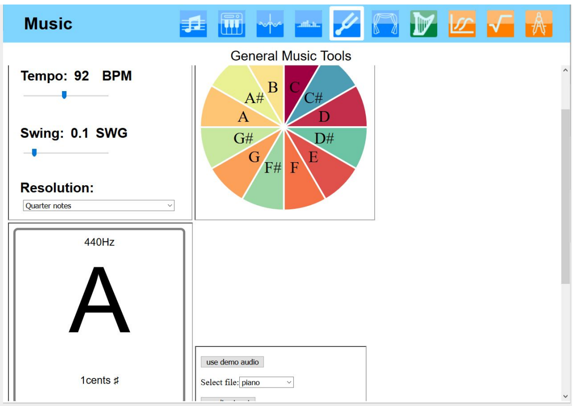
Tones Synthesizer



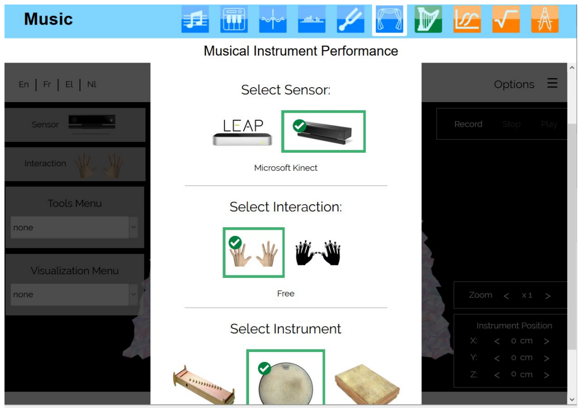
Sound Visualizer



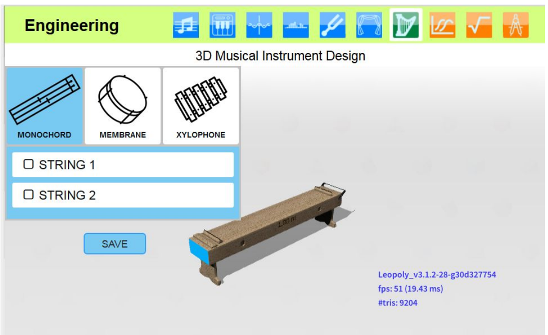
General Music Tools



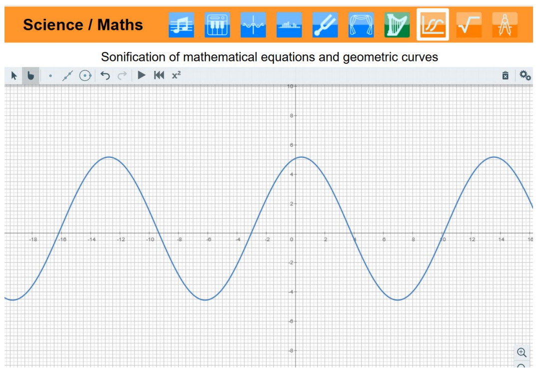
Musical Instrument Performance



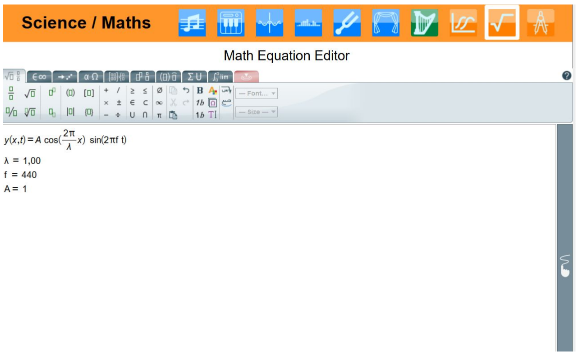
3D Musical Instrument Design



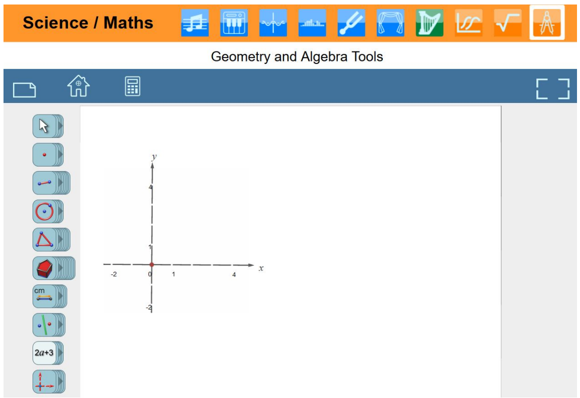
Sonification of mathematical equations and geometric curves



Math Equation Editor



Geometry and algebra tools



3.2. The iMuSciCA pedagogical guide that describes the iMuSciCA scenarios

The iMuSciCA pedagogical guides describe the iMuSciCA scenarios for the teachers. Scenarios are pedagogical units consisting of one of more lessons. The scenarios are concrete lessons suggestions for the teacher so that he or she can work with iMuSciCA in classroom.

The iMuSciCA scenarios are developed in a way that they form pedagogical units in which the iMuSciCA Learning environment can be used in a pedagogical meaningful way. So the scenarios are addressing concepts out of different fields and connect them. The scenarios are meant for a certain age group, they link to curricula (lower of higher secondary education) and above all: they realise the 5 characteristics of the iMuSciCA STEAM pedagogy (see section 2 of this deliverable).

More on pedagogical guide scenarios can be found in deliverable *D2.3 - Initial Educational scenarios and lesson plans for iMuSciCA*, in section 5 where we give a typical example of a use case scenario. In appendix 1 at the end of this deliverable you can find an example of a pedagogical guide scenario.

Here we briefly describe how a scenario looks like and what is the function of the difference parts you will see in a pedagogical guide scenario.

In the beginning of every scenario one can find the following metadata:

1. aimed age group
2. recommended time
3. language
4. learning objectives
5. STEAM fields addressed
6. STEAM inquiry phases addressed*The metadata of iMuSciCA's scenario 'Timbre and Power spectra'.*

A **scenario** is meant as a **pedagogical guide**: it is is described in a way that the teachers can bring iMuSciCA's STEAM pedagoy into their classroom. Apart from the activity description itself a lot of information is found concerning the typical iMuSciCA interdisciplinary pedagogy.

Now we just want to show how a scenario looks like. It consists of different columns indicating:

1. STEAM fields
2. Inquiry phases
3. Time estimation
4. Description of the activity
5. Remarks

So we see that not only the content of the activity is described but also there is room for the typical interdisciplinary iMuSciCA methodology with the 5 strong points of iMuSciCA. Further in section 5, we will stress how the characteristics of iMuSciCA's pedagogy can be found in the scenario.

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

Figure 8. This figure gives an impression of the metadata you can find at the beginning of each scenario. This particular example is meant for upper secondary and consists of two lesson plans. You will find the full scenario in deliverable *D2.3 - Initial Educational scenarios and lesson plans for iMuSciCA*.

On the front page of a pedagogical guide scenario some information is reported, like title of the scenario and the lesson plans, authors, short description, pupils age group, educational objectives. The core of the scenario is presented in the form of a table in which the content is divided in the following categories, indicated for each activity: time needed, inquiry phase, STEAM field, description of the activity, activity itself, remarks including suggestions for the teacher.

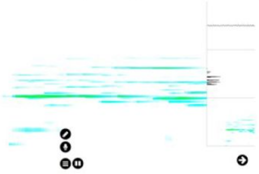
Title: Lesson Plan B2: Investigating the frequency content of a monochord's sound					
Description: In this lesson plan, students will analyze the sounds of everyday life as well as the sound of a virtual monochord and investigate its harmonic content. The lesson pla addressed to upper high school students.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

Figure 9. You see here an example of lesson 2 of iMuSciCA's scenario 'Timbre and Power spectra'. Remark how one of the iMuSciCA tools are used in the activity. You will find the full scenario in deliverable *D2.3 - Initial Educational scenarios and lesson plans for iMuSciCA*.

3.3. The iMuSciCA Learning Content Management System

The teacher has access to an iMuSciCA Learning Content Management System that will help him or her to organise iMuSciCA's STEAM inquiry learning in a practical way. This LCMS will give functionalities like:

- A place to manage users (teachers, students or classrooms).
- A place for students to access learning content.
- A place to display learning content.

You will find more on the technical functionalities of iMuSciCA's LCMS in deliverable *D3.1 - First Version of User interaction with iMuSciCA workbench*. We will stress here how these functions of the LCMS are relevant to iMuSciCA's pedagogy.

iMuSciCA is about cross disciplinary inquiry and students work many times in small groups alternated with whole class communication and reflection moments where the findings of different groups are discussed. Therefore, a Learning Content Management System (LCMS) can help greatly to keep track of student's progress. A teacher can use therefore the LCMS to describe tasks for student groups, add hints to these tasks etc. Students on the other hand can discover how different tasks are related into a broader whole, how different tasks form a larger project.

> For instance, a broad task like 'design your own instrument' might need some scaffolding. For these scaffolding the teacher can choose some existing worked out lessons of iMuSciCA and the teacher can set them ready for the students in a certain sequence. Or, if the teacher likes it, only few hints can be given so that the inquiry stays open. All this is possible with the iMuSciCA LCMS.

Hence, the Learning Content Management system helps the teachers to:

1. Set tasks to students
2. Give them some suggestions on the tools to use for that task
3. Give suggestions on subtasks in order to perform a given larger task or problem
4. To see which tasks, lessons are performed by the students
5. To collect the portfolios or results of student's work
6. Make questionnaires with open and closed questions, to perform some evaluation on student's gained insights and skills

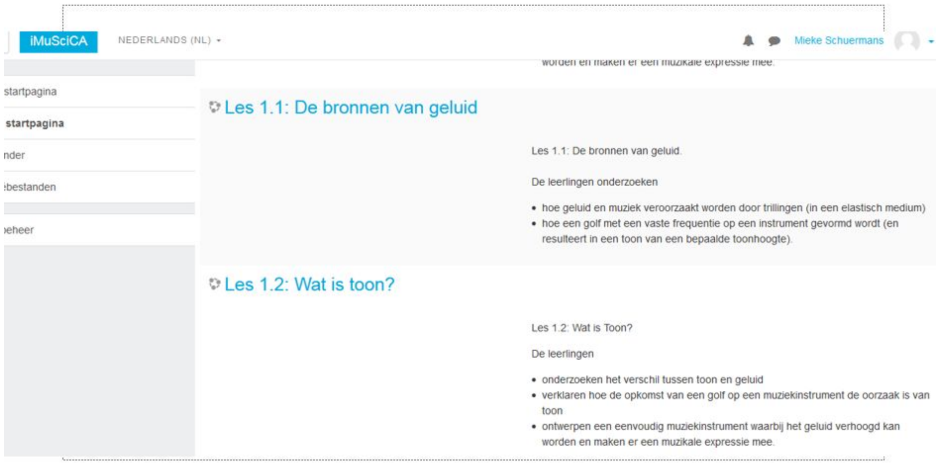


Figure 10. iMuSciCA's learning environment in Moodle, let teachers organise and adapt the different tasks and lessons in a for them and for their class meaningful way

3.4. iMuSciCA scenarios implemented in Cabri Express: Ready to go

Some of the iMuSciCA scenarios are implemented in the Cabri Express environment which is an all purpose math exploratory tool. You can find more on Cabri Express in deliverable [D4.5 - First Version of Music Visualization and Analysis Tools](#).

Cabri Express is available on the workbench and some iMusCiCA lessons are directly available from an URL. This means that every activity foreseen in the scenarios is implemented in slides students can go through. From these slides various iMuSciCA tools are embedded in the pages and students see the tools next to it. This give a smooth and ready to go implementation for direct use in the class. You can start a iMuSciCA Cabri express scenario by just clicking on dedicated urls. The technology works best with the latest Firefox browser.

> Example out of Scenario 1: Lesson 1 on the Sources of Sound and Music. This lesson can be started directly from http://platform.imuscica.eu/workbench.html?clmc=http://download.cabri.com/clmc/ucll/1_Sc_SoundandTone_L1_SourcesofSound.clmc

The iMuSciCA template lessons in the Cabri Express environment are for the moment available only in the student mode. But a teacher mode will become available in the second phase of the project. The interface changes slightly for each mode. The student has access only to the activity itself, while the teacher has in addition access to some tools and other objects in order to *adapt the activity*.

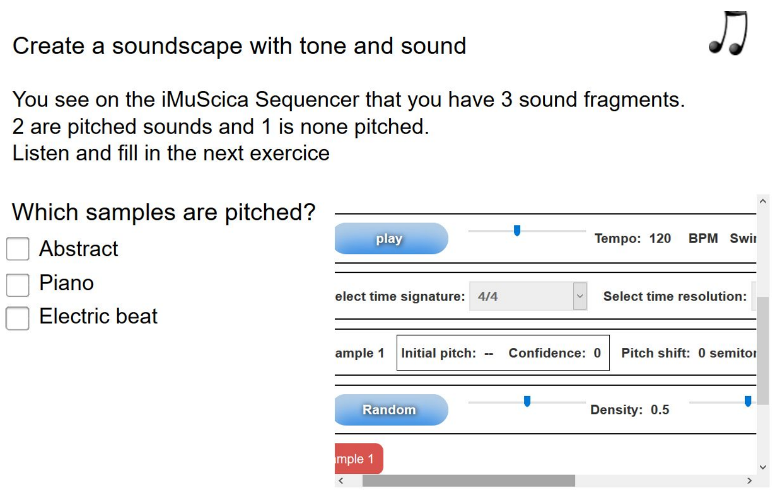


Figure 11. A typical screenshot taken out of a iMuSciCA scenario implemented in Cabri Express. You see how the iMuSciCA Sequencer, one of the tools on the workbench is used. In this case you see a musical activity out of Scenario 1 Lesson 2: Sound and Tone

4. How iMuSciCA's Learning Environment implements iMuSciCA's STEAM pedagogy

In the previous section we learned how the iMuSciCA Learning Environment looks like. It consists of four items:

1. The iMuSciCA workbench
2. The iMuSciCA pedagogical guide that describes the iMuSciCA scenarios
3. The iMuSciCA Learning Management System
4. The iMuSciCA scenarios implemented on the workbench (Cabri Express)

In section 2 we introduced the 5 strong points of iMuSciCA's innovative pedagogical framework:

1. **iMuSciCA's innovative interdisciplinary pedagogy**
2. **iMuSciCA's new Inquiry Learning across STEAM fields**
3. **iMuSciCA's three stages: from guided towards open inquiry** (like in real STEAM-world)
4. **Collaborative and co-creative learning**: in different fields, each fostering the other.
5. **21st century skills**: across different STEAM-fields.

In this section we make clear how these 5 characteristics are shown in iMuSciCA's Learning Environment, in concrete scenarios, in the pedagogical guides. We show here how teachers and students can find back iMuSciCA's pedagogy on everyday's use of the iMuSciCA environment. While in the previous section 3 we talked about the what and the why. This section is about *how* it is done in iMuSciCA's Learning Environment.

4.1. Brings an innovative interdisciplinary pedagogy

Following the recommendations of the American report on STEM education (Honey et al., 2014), the iMuSciCA environment makes the different STEAM fields explicit to learners and teachers. Different fields are marked by different symbols and colours. On the workbench musical, scientific and engineering tools are marked and coloured differently as shown in the figure below.

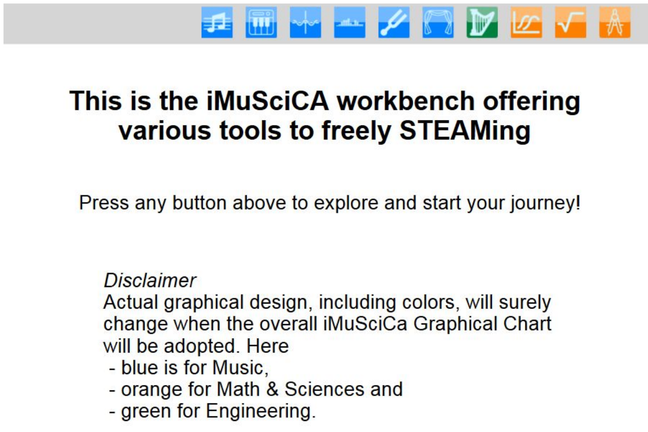


Figure 12. iMuSciCA's workbench landing page (draft version)

In the scenarios, the field is clearly highlighted for the educator (pedagogical guide) but also for learners. The background colour changes whenever the field changes respectively from the musical world to the scientific world or to the engineering world. For the moment these colours are provisional because the overall design is currently be drawn.

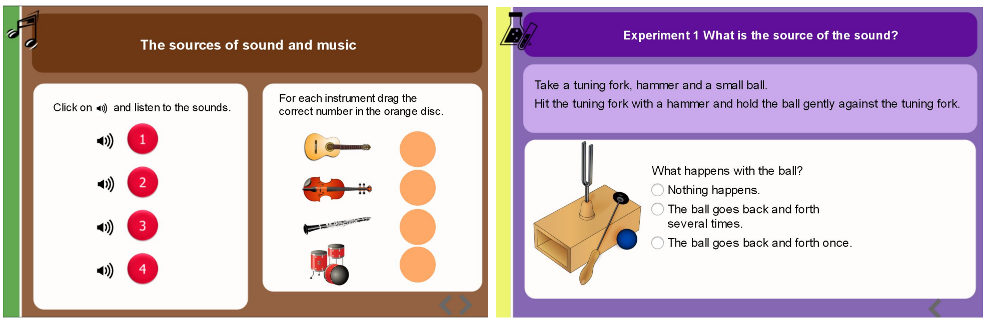


Figure 13. (a) Activity in the music world (b) Activity in the science world

In the pedagogical guide scenario meant for the teacher, there is a seperate column that indicate which of the STEAM fields the activity is in.

4.2. Brings new inquiry learning across STEAM fields

As indicated in the iMuSciCA STEAM-pedagogy and following the recommendations of the American report on STEM Education (Honey et al., 2014), the IBSE phases are made explicit in the iMuSciCA scenarios and lessons, both to the teachers and to the pupils. The idea is to trigger their awareness concerning the learning process they go through so that connections between different types of inquiry in different fields can be made by the learner (Honey et al., 2014).

For the students in iMuSciCA the IBSE phase will be made clear by an icon. The precise icons are currently being drawn. There will be icons for the different inquiry phases.

In the pedagogical guide scenarios meant for the teachers, the IBSE phase is indicated in a separate column.

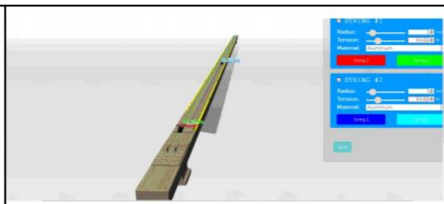
Create	S, E	1	Thales' theorem in bichords A	Teacher introduces the idea of transforming students' segments into strings (uniform scaling is introduced at the teacher's discretion) Students apply measurements of segments as string lengths into a bichord.	 Image 6 LEOPOLY environment is used to produce the different string lengths. Multiple computers may be used to produce all strings Students use LEOPOLY environment to produce different string lengths. At this stage two computers may be used. Their corresponding String-lengths may be adjusted to agree with each other.

Figure 14. An excerpt out of the pedagogical guide scenario 'Let us hear Thales theorem'. The IBSE phase and the STEM field are explicitly indicated in the first two columns

4.3. Three stages: from guided towards open inquiry

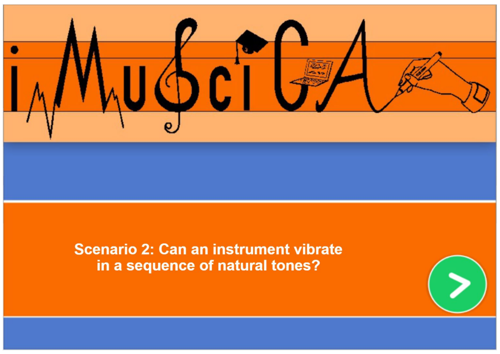
iMuSciCA provides three stages in using its inquiry STEAM pedagogy; from guided inquiry over open but scaffolded inquiry towards free inquiry.

1. ***iMuSciCA's guided Inquiry scenarios***:

   One can just open a template iMuSciCA lesson plan (see also D5.5 - Initial Demonstrators of iMuSciCA workbench toolkits). In this configuration, the iMuSciCA tools are directly available inside the lesson where they are needed (see figure below). Students learn to perform activities in which the needed concepts are introduced in a logical order. In this case the innovative character of the pedagogy lies in the connected way they learn to apply the inquiry phases in different fields like music, science and engineering. They learn to see connections between concepts across different disciplines, hitherto belonging to "separate worlds".

   A guided scenario typically starts in the musical world, from musical experiences, then mostly moves on to the scientific world, where scientific questions and investigations let students discover more of what lays behind that musical experience. The scientific findings on their turn can be applied to the technology or engineering worlds, where pupils use workbench tools or even design a musical instrument. With this virtual (or real) instrument you can make music again and so you end up many times in the musical world where you started. But other pathways with different start and ending points are possible too.

   At the end of each lesson plan concept-maps will be added to make the connections between the treated concepts (in the various fields) clear to teachers and pupils. There is still work in progress to make the learners think more about these concepts. This was also one of the points that came up as a result of the first piloting in schools (See D6.2 - Interim report on teacher's feedback and pilot testing in schools (A-Cycle))



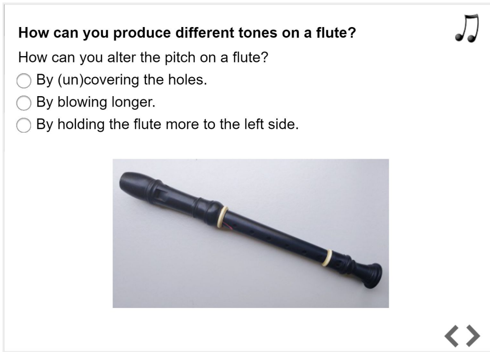


Figure 15. Screenshots from a guided inquiry iMuSciCA lesson ready to go in Cabri Express

For the teachers the iMuSciCA template scenarios are structured in columns in a way that teachers are guided in their every day implementation of iMuSciCA in class. An example of such a scenario for teachers is reported in appendix 1.

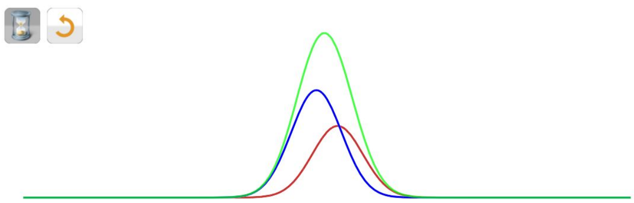


Figure 16. Animations in Cabri Express, like this one about what happens when two waves meet, guide students to an inquiry about properties of waves.

2. iMuSciCA's open inquiry scenarios*:*

The iMuSciCA workbench tools and template **scenarios can offer a framework through which teachers and students can freely move but get some scaffolding when needed**: iMuSciCA supports the learning whenever needed, in order to reach the goal set out by open inquiries.

<u>Example</u>: the **open inquiry scenario 'Design your instrument playing natural tones'**

In order to design an instrument playing natural tones, you need to understand what natural tones are, how do they originate and which parameters influence them. Therefore one can go to the various inquiries in order to learn about these concepts, but one can chose in which order and whether to do all lesson plans or not. So it is more a path of **knowledge on demand**.

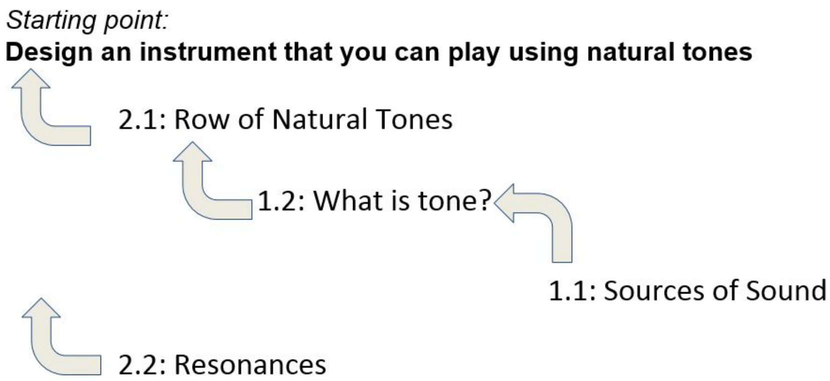


Figure 17. Example of iMuSciCA open inquiry scenario
'**design an instrument playing natural tones'**.

So, you can use the workbench and walk 'your own way' through the iMuSciCA scenarios. In this sense iMuSciCA is quite fostering open inquiry because open inquiry is all about giving the right support at the right time. Because don't forget according to educational research, open inquiries only work if the teacher can appropriately scaffold students [Kirschner et al., 2006]

In the pedagogical guide that goes with these open scenarios the teacher will find some suggestions on different paths that could scaffold these open inquiries.

3. *A free use of the iMuSciCA workbench*

In this third case (activities without pathway) one can use the default workbench available at http://platform.imuscica.eu/workbench.html and freely use the iMuSciCA tools. This can be done by the students themselves or teachers can give some open tasks to students. In such open tasks students have to 'look around' on the workbench in order to answer questions and perform tasks.

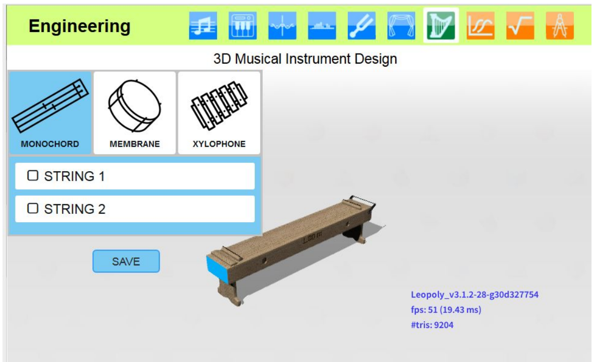


Figure 18. The iMuSciCA workbench with the 3D musical instrument design: Students can use this environment freely to inquire about designing their own instrument.

4.4. Fosters collaborative and co-creative learning

Every iMuSciCA scenario and lesson is structured around small group activities that fosters active learning: it engages students from different perspectives (and the teacher more in a role of facilitator). Therefore teaching and learning is a shared experience. So it is easy for students to contribute to group activities: some of them can help performing music, another one can conduct an instrument, a third one can built some simple instruments or just experiment on the virtual design environment. So it is here also the interdisciplinary character of iMuSciCA that fosters active collaborative and co-creative learning more than is the case in single subject teaching (See also section 2.4 and 2.5 on how iMuSciCa's is bringing collaborative learning and 21st century skills effectively into the classroom.)

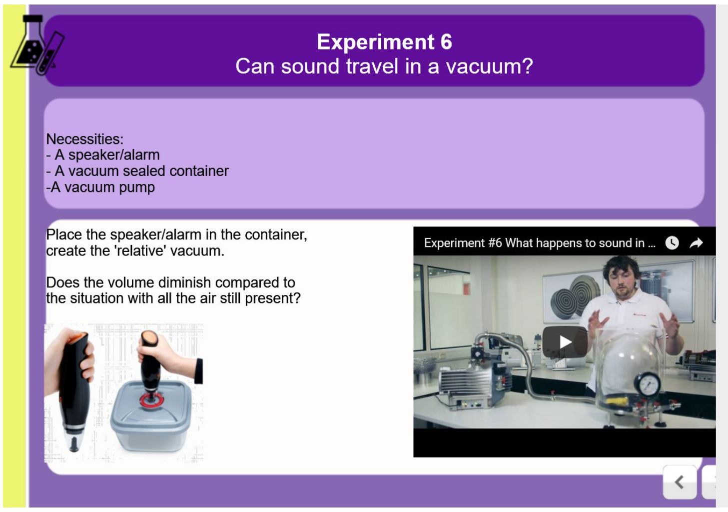
After a series of inquiries the iMuSciCA methodology asks students to reflect and communicate on their findings and share their thoughts with the rest of the group and with the teacher. That's the point where the collaborative learning is shared from the particular student group with the rest of the class. You will find in the pedagogical guide scenarios IBSE phases like 'Communicate & Reflect' where the students have to step back and think about their findings, inquiries, thoughts etc. By communicating their findings they will get reflections and questions from other groups (21st century skills) and if that is not enough, the teacher may still play a role in scaffolding this. So here new roles come in, like 'reporter of the findings', organiser… etc. It might be important to change roles after a while so that every student gets acquainted with different aspects of the inquiry process and the work in small groups.

Figure 19. iMuSciCA's interdisciplinary collaborative and inquiry learning in action in an class (an iMuSciCA pilot class in the Agnetencollege, Peer, Belgium)

Example of a small group inquiry activity

This example belongs to the iMuSciCA scenario 'The sources of sound'. The scenario is full of inquiries in different worlds: the musical one, the scientific one and the engineering world. It ends with an activity in the musical world where they have to build and play with a bottle organ (tinkering!). Typically all these activities are done in small groups.

You will also find activities where students, after some inquiries, have to perform a 'Communicate and Reflect' phase.

			Can sound propagate in the vacuum? **Observation** You hear the sound less and less hard while pumping and creating the vacuum. **Conclusion:** Sound cannot propagate in the vacuum because there are no air particles. Therefore no pressure wave can originate.	*Slide 14:* 	**Experiment:** Place a speaker or an alarm in a vacuum sealed container and use a pump to create the vacuum inside the container. Let the speaker/alarm make sound. **Alternative**: In case you don't have the right material, you can watch this video: https://www.youtube.com/watch?v=oY_9hKdTG8o&feature=youtu.be
	Analyse Communi-cate Reflect	S	What did you discover? Discuss and come to conclusions.	1. What is always the actual source of a sound, in what does it originate? 2. What vibrates in the 4 different families of instruments? 3. Is it necessary that the vibrating medium is elastic? Why? 4. Through what does the sound propagate until your ear? 5. What this has to do with waves? 6. In a sound wave: do the air particles really move? Or are they just compressed and decompressed?	During this 'contact moment' the pupils reflect on what they learned. They present their conclusions to the teacher and the other pupils by answering to questions of the teacher (see questions in the central column as an example).
	Create Design	E/M	Build a simple idiophone (with a bottle filled with water), aerophone (with a bottle filled with water), chordophone (a box with a rubber band) and a membranophone (a box with a balloon wrapped around the top)	*Slide 15:*	Students experience what they have learned about the sources of sound in a real musical-praxis environment. **Suggestions**: You can build the bottle as idiophone by partially filling the bottle with water: hit then the

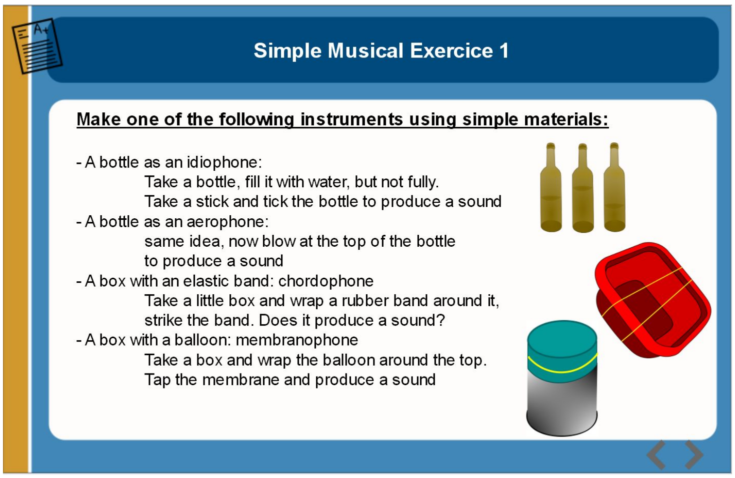
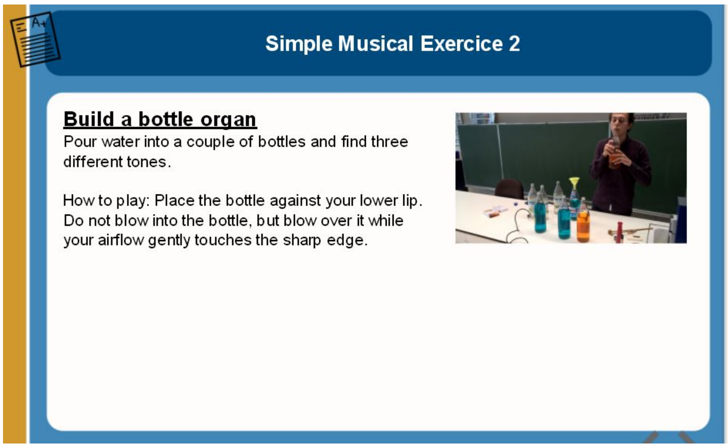
					bottle with a stick to make sound. You can build a bottle as aerophone by filling it partially with water: blow then in the bottle to obtain sound.
2	Create Design	M	Build a bottle organ and play with it. 	*Slide 16:* 	**Suggestion**: when looking for the tones, it is useful to have a pupil which follows a music course in each group, whenever possible.

Figure 20. Here you see excerpts out of the scenario 'The sources of sound'. The scenario is full of small group inquiries in different worlds.

You see in this scenario how **tinkering** is also involved: built your own simple instrument, built your own bottle organ. STEM-rich tinkering activities are designed to support *interdisciplinary* investigations and creativity because they are using a STEM-rich palette of tools, concepts, and phenomena (See Section 2, [Honey & Kanter, 2013 ; Martinez & Stager, 2013])

In these tinkering challenges a lot of collaborative skills and insights are requested.

4.5. Addresses 21st century skills

By using the context of music, iMuSciCA makes learning STEM-content relevant. In a classical model of education, teachers transmit factual knowledge to students via lectures and textbooks, which are bound to a certain subject matter like mathematics, physics, etc.

In the iMuSciCA learning environment on the other hand, students go smoothly over from one field to another, real and virtual experiments are performed, instruments can be designed or played with, and by doing so, students practice transferring skills and knowledge to different fields and contexts in a very natural way. iMuSciCA students learn to work collaboratively to gain insights and skills into new and different contexts, to be creative and solve new problems. The iMuSciCA pedagogy and environment make it easier for new insights to emerge from the different activities in the different contexts, each context contributing to the construction of one facet of a new insight or skill in one particular field. But this gain in one field is directly connected to gain of skills and insights in another field. This is what 21st century skills are all about (See also section 2.5).

In all of iMuSciCA scenarios you will find many instances where 21st century skills like creativity, initiative and collaboration are at stake and typical for iMuSciCA this is done *through different subject matter fields* (and not separately like in standard approach). iMuSciCA's pedagogy is therefore in line with the '9 lessons' for a pedagogy that addresses 21st-century learning [Saavedra & Opfer, 2012]. See section 2.5 for more explanation.

Example 1 on how iMuSciCA works on transfer between different fields. Example of iMuSciCA scenario 'Let's hear Thales theorem'.

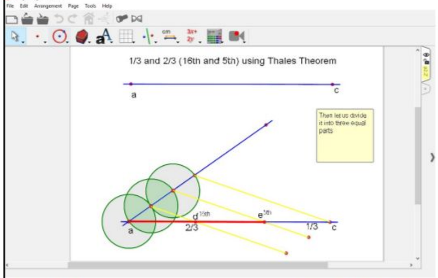
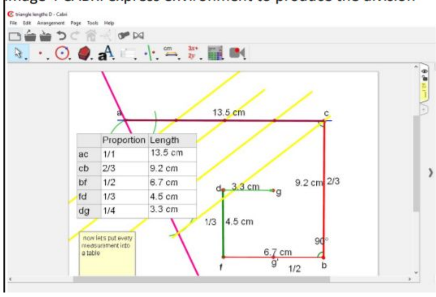
Engage	S	1	Thales' theorem	Teacher recalls the Thales Theorem and asks students to study the division of their own string lengths in 3, 4 and 5 parts. They express each segment in terms of proportions. They measure the lengths of each segment according to these proportions. Results appear on table.	 Image 4 CABRI express environment to produce the division 	nage

Figure 20. Here you see excerpts out of the scenario 'Let's hear Thales theorem' where a concept out of mathematics (Thales theorem) is connected to musical proportions and intervals (octave, fifth, fourth, third…) on the one hand and to the engineering 3D design tool on the other.

Example 2 on how iMuSciCA works on transfer between different fields. Here transfer is illustrated between concepts of science and creativeness in the musical world (Example taken from scenario 1 Lesson 2: Sound and Tone)

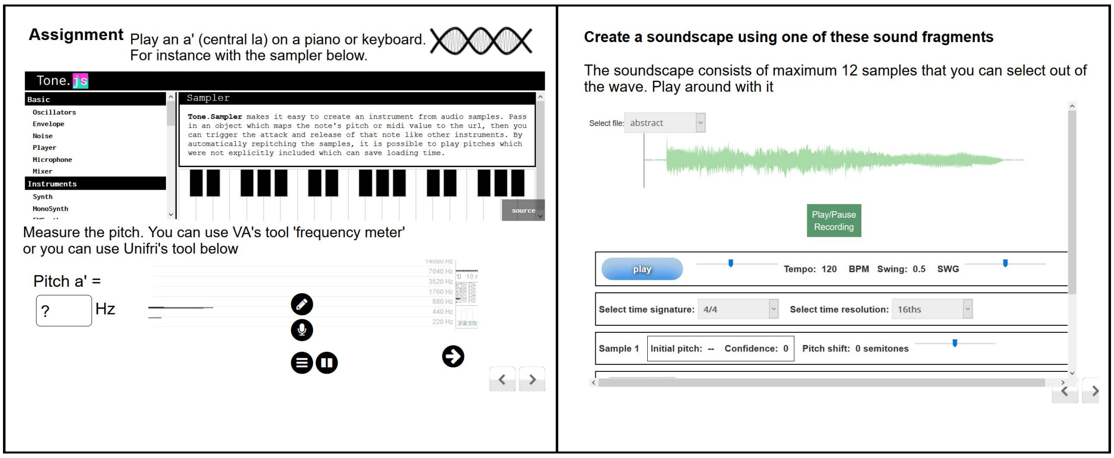


Figure 21. Here you see an activity out of iMuSciCA's scenario 'Sound and Tone': it applies scientific concepts about tone or noise learned some moments ago. They learn to be creative with them again but now in a context of music.

5. An iMuSciCA Use Case Scenario: design your own music instrument playing natural tones

Here we illustrate the overall value of iMuSciCA's pedagogy by means of a concrete example scenario. The example scenario is: ***design your own musical instrument playing natural tones***.

5.1. A motivating scenario: design your own instrument

The goal of *designing and playing an own instrument* motivates students to move forward and to get to learn the core concepts and skills in three different STEAM fields (music, science and engineering). Although an attractive goal can help in getting some situational interest (that will last for a relatively short time), the deeper and intrinsic motivations comes from within (see Ryan & Deci, 2000): the question is to trigger the desire to understand main concepts or to perform an integrated task like performing on a self designed music instrument. In any case, in iMuSciCA concepts and skills of three different fields ***are combined*** *and the challenge is to get the* ***whole picture*** *and* ***build and play the instrument.*** So the interdisciplinary nature of iMuSciCA makes the learning more relevant to learners which increases the possibility to trigger intrinsic motivation (21st century skills).

We will illustrate below how a scenario like this one is built around some core concepts and skills out of music, of science and of engineering. Skills and concepts in and between those fields are different but related. Students should figure out how natural tones are looked upon and played with in the music world, how they relate to concepts of eigenfrequencies in the scientific world and how you can use all these insights to technical build a virtual and real musical instrument.

5.2. Concepts & skills and their connections between different STEAM fields

Design an instrument that you can play using natural tones - Concepts and Skills

In the table below we give the different concepts and skills touched upon in each field. You can discover how iMuSciCA interweaves them in order to make learning relevant and how it connects to skills in different fields too (like conducting experiments, using a design environment, building an instrument or playing an instrument).

Music	**Science/Maths**	**Engineering/Technology**
Pitch	**Pattern** in frequencies, waves	
Playing tones on a instrument without changing the length or any other parmeter	**Unchanged constraints**: length, tension, linear density.	**Virtual musical instruments,** producing natural tones
Natural tones	Row of **standing waves**, eigenfrequencies, resonant frequencies (physics). **Row** of integer multiples (mathematics).	**Building techniques** to make musical instruments where parameters of length etc. aren't used.
Melody with **natural tones**		**Application** of your **designed instrument** in the real world.

The concepts used in each scenario are schematically summarized at the end of each lesson plan, so to make them explicit to the learner too (this is at present work in progress).

5.3. Typical implementation in the iMuSciCA Learning Environment

The educational objectives of this scenario are:

1. to recognise the fact that strings and air columns have certain resonant frequencies
2. to discover a certain row of standing waves that causes these precise resonant frequencies
3. to discover that altering boundary conditions like length, tension and density, changes the pitch of the fundamental
4. to apply these insights in designing a simple instrument

This scenario can be implemented:

1. As a guided inquiry scenario
2. As an open inquiry scenario

5.3.1. Implemented as a guided inquiry

First we give the outline of standard guided inquiry. It starts in the musical world, connects to maths and physics and goes on to engineering while returning at the end to music again.

Design an instrument that you can play using natural tones - Guided inquiry path -
Connecting different fields

Music	**Science/Maths**	**Engineering/ Technology**
Starting point: context **Music**		
Listen: **row of tones** from low to high. Is there a pattern? → **Musical pattern**	**Mathematical pattern?**	
Natural tones	Measure the eigenfrequencies in the **science** world. Recognise a pattern of integer multiples (mathematical pattern). Explanation?	Use of **tools** that can **measure** frequency of tones.
	Why does a precise serie of natural tones occur? Model of possible waves (standing waves) occurring as superposition of reflecting waves at the ends of the string or tube	Experiment with natural tones on real and **virtual instruments**.
How you change the pitch of a fundamental tone on an instrument?		Build a basic musical instrument which uses natural tones, make a fundamental tone in e.g. C
	Same question but now in scientific world: How you change the pitch of a fundamental tone on an instrument? Investigate how the boundary conditions of length, tension, density... Alter the pitch	Use tools on the workbench to investigate

Music: make a simple melody with natural tones on your self designed instrument!		On the iMuSciCA 3D environment: verify it the calculated length or other boundary condition has indeed the right row of eigen frequencies

5.3.2. Implemented as an open inquiry scenario

A more open version of the scenario can start from the 3D Musical instrument tool and from there bounce back on questions like:

3D instrument design tool of iMuSciCA trying to make natural tones instrument.

1. What are natural tones? In Music, in Science

2. How do we change the pitch of the fundamental?

3. Return to 3D Musical instrument design tool to make your natural tones instrument

Depending on the scaffolding the teachers will give, parts of the guided scenarios can be given but now they are followed in another order.

6. iMuSciCA brings innovation to national curricula

6.1. No STEAM on the standard curricula, but teachers are willing to connect arts to science

Joining science, technology, engineering, mathematics and art is far from evident also from the curriculum point of view. Our detailed study of the curricula in France, Belgium and Greece showed that nowhere in the standard curricula, a pedagogy connecting Music with Science and Engineering, can be found. So iMuSciCA is fostering renewal on this point too.

Out of first reactions of teachers during the first piloting phase, in all countries we found teachers very open to the connection iMuSciCA wants to make: connecting Music, which is considered as not connected at all, to science and engineering. It is a huge challenge but one worth trying.

6.2. Per country possibilities to connect iMuSciCA's innovative pedagogy to the standard curriculum

However, how new iMuSciCA might be to the curriculum, it is necessary to connect it with the standard curriculum after all. That's why we performed a detailed study of lower and upper secondary in France, Belgium and Greece for the subjects of Physics, Maths, Engineering (if any) and Music. The conclusion is that there are some possibilities in the current curriculum to connect iMuSciCA's to the curriculum. We give for each country some synthesis of the possibilities. You can find more details in Appendix 3.

6.2.1. In 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.

6.2.2. In 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.

6.2.3. In 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 3rd grade of Junior High School and the 1st grade of Senior High School (student ages of 14-15 years) throughout which the curriculum displays higher affinity with the iMuSciCA science and maths related content. Music Schools in Greece display a special case study, as the iMuSciCA interventions can be integrated both during the course of science related subjects, similar to the public and private schools in Greece, as well as during the course of specialized music and music technology related subjects provided in the framework of the Music School curriculum.

7. Conclusion

Joining science, technology, engineering, mathematics and art is far from evident in education. This could be directly inferred from our curriculum study where was shown that nowhere in standard curriculum a pedagogy connecting Music with Science and Engineering, can be found. Traditional IBSE phases need for instance to be broadened so as to let room to activities not usually incorporated in science inquiry. Not easy for schools like they are organised now.

Indeed, from first piloting in schools we see that there are some conditions needed for good functioning of iMuSciCA pedagogy, among them:

- the necessity of a team of teachers from several disciplines
- importance of a good planning and organisation of the students' activities
- necessity of enough scaffolding (and time!) for allowing an interdisciplinary IBSE pedagogy
- To optimize further the tools and template lessons as well as give hints how to use them in more open inquiries

The iMuSciCA team will go on developing and experimenting with all these in the three different countries involved in this project, the consortium hopes to elicit these conditions further and create a useful iMuSciCA learning environment to bring all this to classroom. So, iMuSciCA works further and hopes to bring a working and ready to go interdisciplinary STEAM Pedagogy to the classroom, one that connects hitherto unconnected fields. This pedagogy includes an innovative methodology that brings in learning by inquiry, collaborative and co-creative learning and that focuses on 21st century skills.

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Appendix 1 - Example of pedagogical guide that describes a scenario

Lower Secondary Scenario 1: Sound and Tone

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

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

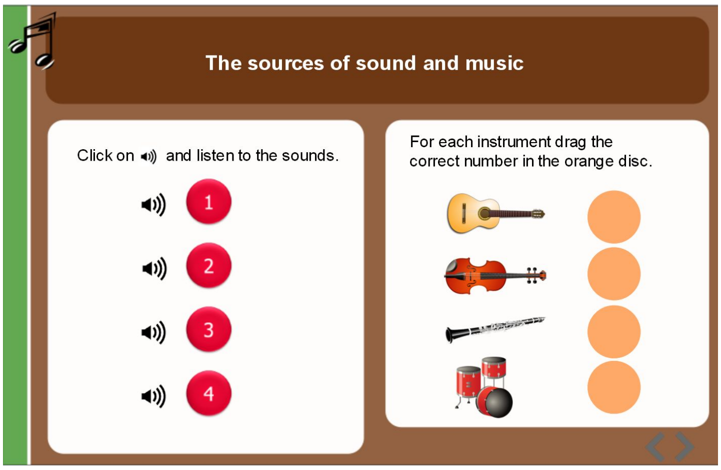
<table>
<tr><td>Title:</td><td colspan="3">Lower Secondary Scenario 1: Sound and Tone</td></tr>
<tr><td>Keywords:</td><td colspan="3">periodic, frequency, wavelength, pitch, sound, tone</td></tr>
<tr><td>Short Description:</td><td colspan="3">iMuSciCA Scenario around basics of sound and tone, aimed at lower secondary</td></tr>
<tr><td>Lesson Plans included:</td><td>Lesson Plan 1.1: The sources of Sound
Lesson Plan 1.2: What is Tone?</td><td>Date:</td><td>26/08/2017</td></tr>
<tr><td>Educational Objectives:</td><td>The following scenario let students inquire:
Lesson 1.1: The sources of Sound
i) how sound and music originate as vibrations (in an elastic medium)
ii) how a wave with a fixed frequency is formed on an instrument (that produces a tone of a certain pitch).
Lesson 1.2: What is Tone?
i) Investigate the difference between tone and noise.
ii) Explain how the emergence of a wave on a musical instrument is the cause of tone.
iv)Design a simple musical instrument that can raise sound and make a musical expression with it.
v) Extra: Why are waves of tones quite undulating?</td><td>Estimated Duration:</td><td>3-4h</td></tr>
<tr><td>Author(s):</td><td>Renaat Frans</td><td>Age Group:</td><td>Lower Secondary (approx. 12-15)</td></tr>
</table>

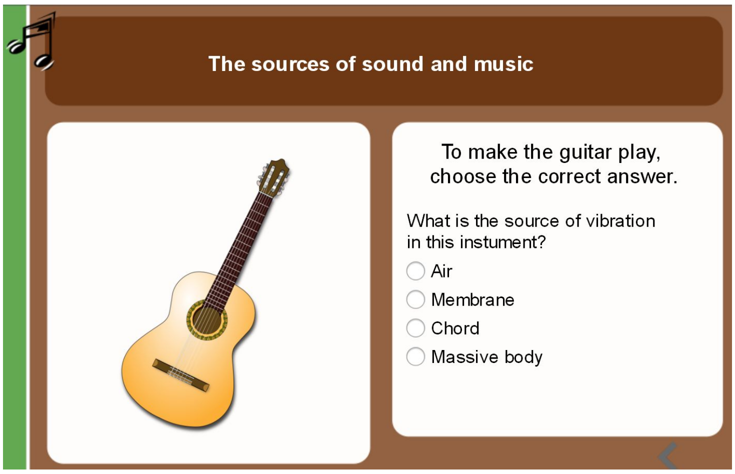
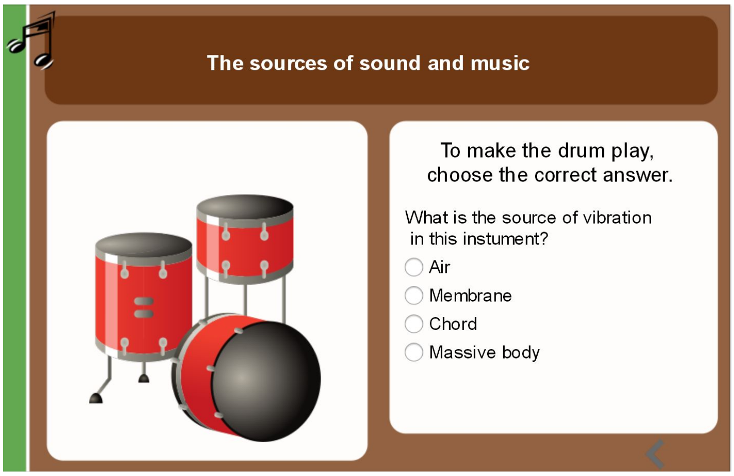
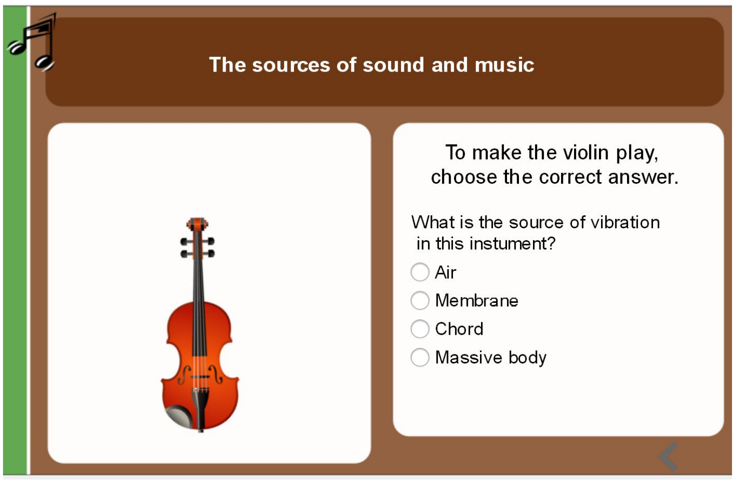
Contributor(s):	Erica Andreotti, Mieke Schuermans, Jeroen Vanesser, Lander Frans, Jeroen Op den Kelder, P. Stergiopoulos, E.Chaniotakis	Language:	English
Status:		Difficulty Level:	Low
Dissemination level:		Special Needs Addressed:	

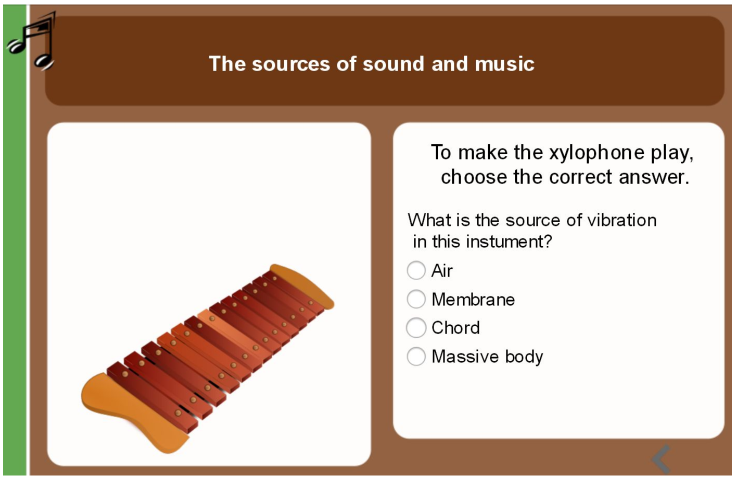
Lesson Plan 1.1: **The sources of Sound - Detail**

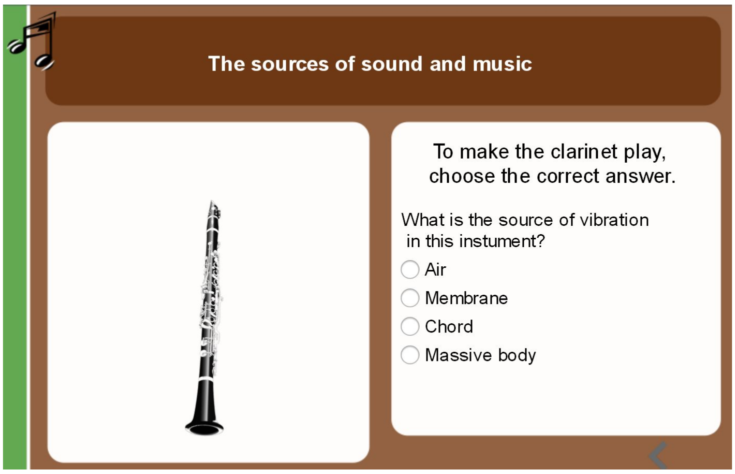
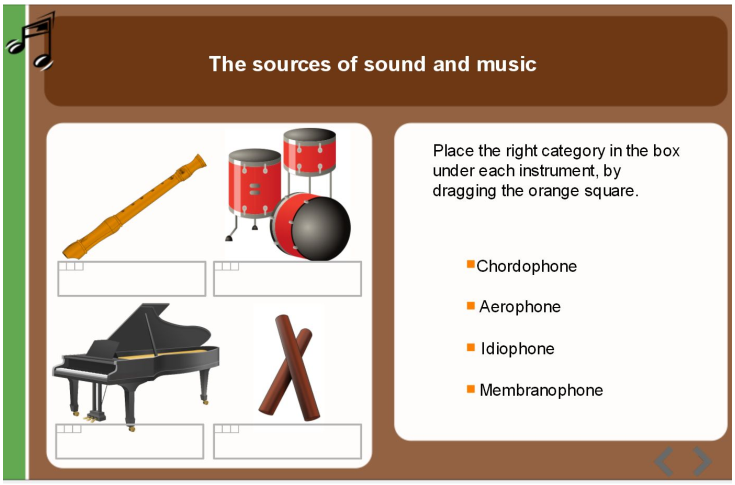
No specific pre-knowledge is required. Typically pupils work in groups of maximum 3 with a computer and a box with the needed material. After a short introduction, the teacher goes around, observes and guides the pupils whenever needed.

Concerning the evaluation, it is important to make time for ‘contact moments’: this way the teacher can observe what the pupils really understood and repeat the basic concepts of this lesson. It is possible for example to organise a sort of game with ‘thesis’, in which pupils have to say whether these are correct or not and in case of wrong thesis they have to correct them.

Time	Phases	Field	Description	Activity	Remarks
1 hour	Engage	M	Sounds of different instruments are played. The pupils have to recognize to which category they belong in terms of ‘what is vibrating’.	*Slide 2:* 	We start in the musical world. Which sound is produced by which instrument? **Solution**: Guitar - 2 Violin - 1 Clarinet - 4 Drum- 3

	Imagine/ Investigate	M	Various instruments are shown. What could be the source of vibration in these instruments?	*Slide 3 - 7:*   	**Solutions:** Guitar - chord Drum-membrane Violin - chord Xylophone - massive body Clarinet - air It is important that the pupils read the comments in Cabri.

<table>
<tr><td></td><td></td><td></td><td></td><td>

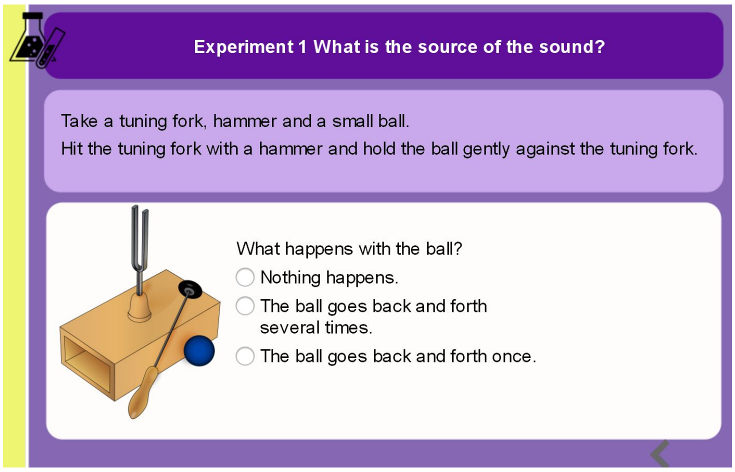
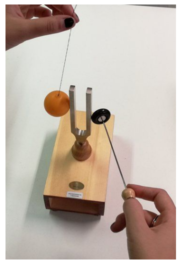

</td><td></td></tr>
<tr><td></td><td>Analyse</td><td>M</td><td>According to ‘what is vibrating’, one can distinguish at least 4 families of musical instruments.</td><td>Slide 8:

</td><td>These are our first conclusions in the musical world.

Solutions
Flute - Aerophone
Drum - membranophone
Piano - chordophone
Blocks - idiophone</td></tr>
</table>

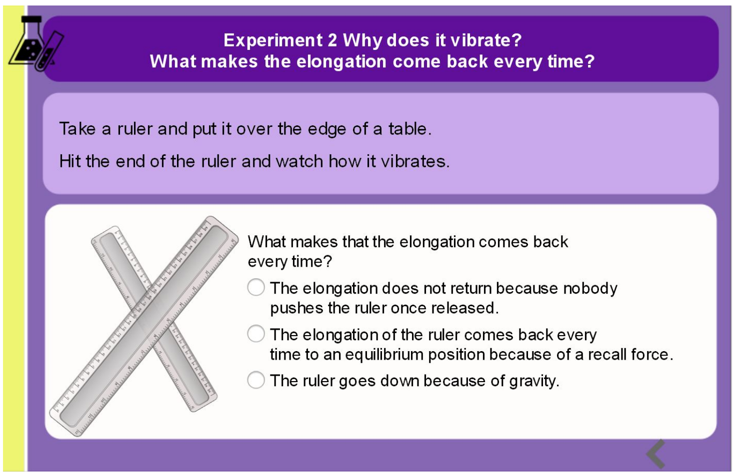
<table>
<tr>
<td></td>
<td>Investigate</td>
<td>S</td>
<td>By means of simple experiments: can we observe what is vibrating?

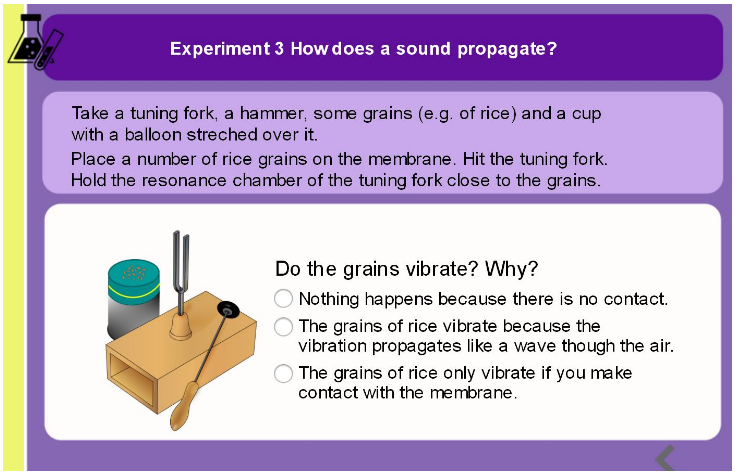
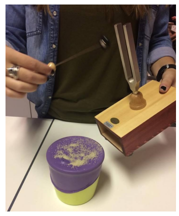
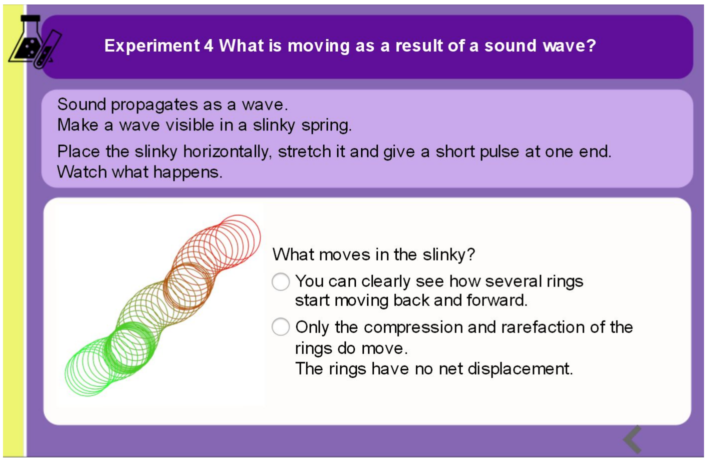
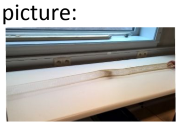
Observation

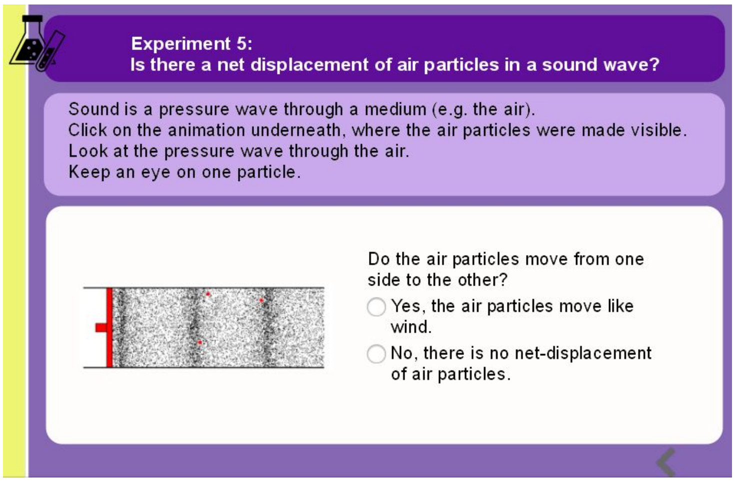
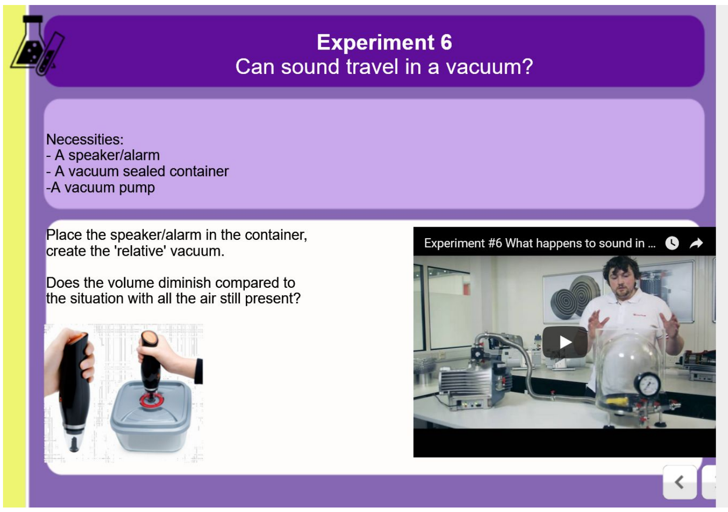
The ball vibrates trilt back and forth.

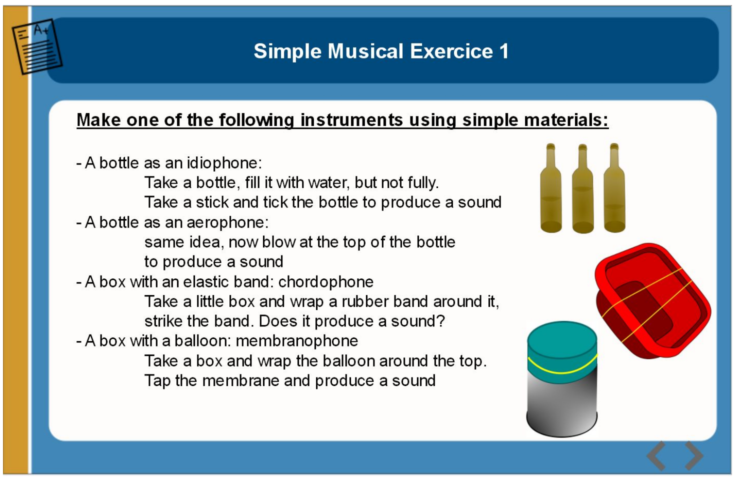
Conclusion:
Sound is a vibration.</td>
<td>Slide 9:

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

Hit the tuning fork while holding the ball against the tuning fork, but not touching it (about 0,5 cm away).</td>
</tr>
<tr>
<td></td>
<td>Investigate</td>
<td>S</td>
<td>Observe a vibration more carefully: why does the elongation come back every time?

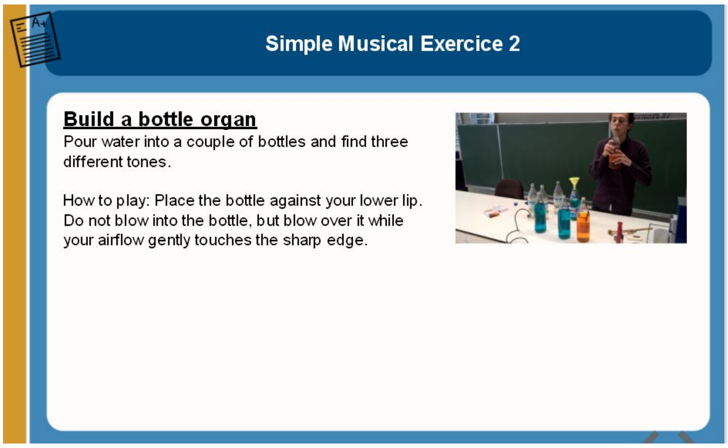
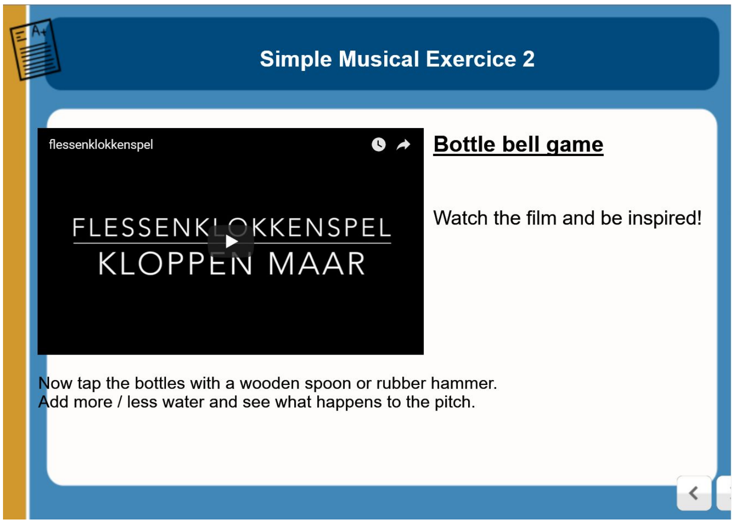
Observation
The extremity of the ruler comes back every time to an equilibrium position because of a recall force.

Conclusion:
A vibration is produced by a repeated movement.</td>
<td>Slide 10:

</td>
<td>Experiment:
Place the ruler at the edge of a table as shown in the picture. Hit the extremity and let it vibrate.
</td>
</tr>
<tr>
<td></td>
<td>Investigate</td>
<td>S</td>
<td>Can a sound propagate without making contact?</td>
<td>Slide 11:</td>
<td>Experiment:
Place the grains on the balloon stretched over the cup. Hit the tuning fork while</td>
</tr>
</table>

			Observation The grains vibrate because the vibration propagates through the air. **Conclusion:** Sound is a vibration that propagates in a medium, such as air.		holding the resonance chamber close to the grains like shown in the picture below. 
	Investigate/ Analyse	S	Sound propagates as waves through the air: what does move in a wave? **Observation** Only the compression and rarefaction of the rings do move. The rings come back to their original position and netto they do not move. **Conclusion:** This movement is analog to the movement of the soundwave in the air.	*Slide 12:* 	**Experiment:** Make a wave visible in a slinky. Do this by placing the slinky horizontally on a table, stretching it and giving a pulse at one end like shown in the picture:  Suggestion: use a slinky with small spring constant in order to optimize the effect.

			Watch the following animation of a pressure wave through air: https://giphy.com/gifs/longitudinal-wave-xTiN0JzYz3s4cBS6QM Observe one specific air particle (red points): do the particles move from one side to the other? **Observation** The air particles do not move from one side to the other and there is no net displacement **Conclusion**: The air particles move back and forth around their initial position. Sound is a pressure wave in the air.	*Slide 13:*  	
			Can sound propagate in the vacuum? **Observation** You hear the sound less and less hard while pumpinig and creating the vacuum. **Conclusion:** Sound cannot propagate in the vacuum because there are no air	*Slide 14:*  	**Experiment:** Place a speaker or an alarm in a vacuum sealed container and use a pump to create the vacuum inside the container. Let the speaker/alarm make sound. **Alternative**: In case you don't have the right material, you can watch this video: https://www.youtube.com/watch?v=oY_9hKdTG8o&feature=youtu.be

			particles. Therefore no pressure wave can originate.		
	Analyse Communi-cate Reflect	S	What did you discover? Discuss and come to conclusions.	1. What is always the actual source of a sound, in what does it originate? 2. What vibrates in the 4 different families of instruments? 3. Is it necessary that the vibrating medium is elastic? Why? 4. Through what does the sound propagate until your ear? 5. What this has to do with waves? 6. In a sound wave: do the air particles really move? Or are they just compressed and decompressed?	During this 'contact moment' the pupils reflect on what they learned. They present their conclusions to the teacher and the other pupils by answering to questions of the teacher (see questions in the central column as an example).
	Create Design	E/M	Built a simple idiophone (with a bottle filled with water), aerophone (with a bottle filled with water), chordophone (a box with a rubber band) and a membranophone (a box with a balloon wrapped around the top)	*Slide 15:*  	Students experience what they have learned about the sources of sound in a real musical-praxis environment. **Suggestions**: You can build the bottle as idiophone by partially filling the bottle with water: hit then the bottle with a stick to make sound. You can build a bottle as aerophone by filling it partially with water: blow then in the bottle to obtain sound.

2	Create Design	M	Build a bottle organ and play with it. 	*Slide 16:* 	**Suggestion**: when looking for the tones, it is useful to have a pupil which follows a music course in each group, whenever possible.
	Create Design	M	Build an idiophone with bottles and play it as a bell game.	*Slide 17:* 	Watch first the video as inspiration.

Appendix 2 - 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 as to let room to activities usually not incorporated in science inquiry**. The phases have, although connected, indeed slightly different meanings in the different STEAM fields. Therefore iMuSciCA introduces the following STEAM Inquiry phases that imply inquiry in and between the fields, that 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			
STEAM Inquiry Phase		**Music**	**Science /Math**	**Engineering /Technology**
	Engage	*Lesson 1*		
	Imagine		*Lesson 1*	
	Create *Investigate/Design*	*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 field			
		Music	**Science /Math**	**Engineering /Technology**
STEAM Inquiry Phase	**Engage**	*Lesson 1*		
	Imagine		*Lesson 1*	
	Create *Investigate/Design*	*Lesson 1*	*Lesson 1*	*Lesson 1*
	Analyse		*Lesson 1*	*Lesson 1*
	Communicate & Reflect	*Lesson 1*	*Lesson 1*	

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', as shown in figure 1; 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 version 2 of this deliverable concepts translated into for the students meaningful situations or problems, will be illustrated based on the initial educational scenarios (D2.3), currently under development. We will given 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, the 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 the appropriate places) to cause the same effect. In order to do so they need practical musical knowledge (field M) 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 differentiate conceptual view useful for further investigation or design.

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-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-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. Come to sound conclusions (Science-Mathematics)
- Make an evaluation of the creation and, if needed, optimise 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 3 - 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.

3.2.1. In France

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

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

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

<u>France: Higher cycle of secondary: lycées (15 to 18 year-old students)</u>

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.

3.2.2. 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.

<u>Belgium: Secondary school 1st stage (Middenschool) – 2nd year (12-14 years-old)</u>:

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.

3.2.3. 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.

1st grade of Junior High School

Subject "Mathematics"

- Chapter on equations
- Chapter on triangles and geometric shapes

2nd grade of Junior High School

Subject "Mathematics"

- Chapter on functions and graphs
- Chapter on geometric solids

3rd 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

3rd 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 1st and 2nd grade "Lyceum" (Upper secondary) supporting the implementation of iMuSciCA learning scenarios related to Physics and virtual technology. Furthermore, students experiment with the development and manipulation of waveforms. They discover their properties by changing their characteristics using computer software oscillators and synthesizers. They also experiment with spectral analysis as part of the principles of digital recording.

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 3rd grade of Junior High School and the 1st grade of Senior High School (student ages of 14-15 years) throughout which the curriculum displays higher affinity with the iMuSciCA science and maths related content. Music Schools in Greece display a special case study, as the iMuSciCA interventions can be integrated both during the course of science related subjects, similar to the public and private schools in Greece, as well as during the course of specialized music and music technology related subjects provided in the framework of the Music School curriculum.