Interactive Music Science Collaborative Activities

Team Teaching for STEAM Education

Deliverable 2.1

Initial Pedagogical framework and iMuSciCA use cases by learners and teachers

Date:	30/6/2017
Author(s):	Renaat Frans (UCLL), Erica Andreotti (UCLL)
Contributor(s):	Petros Stergiopoulos (EA), Manolis Chaniotakis (EA), Israel Fenor (WIRIS), Daniel Martín-Albo (WIRIS), Vassilis Katsouros (ATHENA), Colette Laborde (CABRI), Pierre Laborde (CABRI), Marcus Liwicki (UNIFRI), Robert Piechaud (IRCAM), Zoltan Karpati (LEOPOLY)
Quality Assuror(s):	Colette Laborde (CABRI), Evita Fotinea (ATHENA)
Dissemination level:	PU
Work package	WP2 – Pedagogical framework and pedagogical engineering for teaching STEM with Music
Version:	1.0
Keywords:	STEAM, Pedagogy, Learning, Workbench, interdisciplinary, teachers, students
Description:	Report on the initial pedagogical framework and the iMuSciCA use cases for team learning/teaching by learners and teachers.

Horizon 2020
European Union Funding
for Research & Innovation

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

Executive Summary

iMuSciCA presents an interdisciplinary STEAM Pedagogy that connects different disciplines with each other, that will bring new pedagogical methodologies in classroom, with the use of state of the art educational technology tools, so that active, discovery-based, deeper and more engaging learning can be facilitated: with opportunities for collaboration, co-creation and collective knowledge building.

Therefore, the iMuSciCA STEAM pedagogy foresees typical activities starting in the musical world, from musical experiences, while moving 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 in the technology or engineering worlds where they design for instance a musical instrument they are really going to play with. But also other pathways with different start and ending points are possible. In any case, students experience a 'many worlds' journey through these different STEAM fields and learn how inquiries in those different fields differ but are indeed connected at the same time.

iMuSciCA will work mainly with schools where teachers from different backgrounds cooperate. Indeed like in the real STEAM world, in research institutes or in companies for instance, where one can find interdisciplinary teams too. So the team of teachers in school as well as the collaborative activities of students in class reflect that diverse world of STEAM.

In order to make this pedagogy happen in classroom, the usability of the tools developed by the iMuSciCA consortium is crucial. Therefore, one can also read about how iMuSciCA can connect to the curriculum in France, Belgium and Greece. The most promising connections are mainly in lower secondary although higher up some others can be also found.

Moreover, this deliverable on the STEAM pedagogy also reports on the first concrete outlines on how the iMuSciCA workbench will look like, how it can be typically used by students, teachers and authors. An initial list of available technologies will be also provided. These technologies will be embedded into the iMuScicA learning environment and are subject to the work of other work packages for the implementation and integration work.

Version Log			
Date	**Version No.**	**Author**	**Change**
10-05-2017	0.1	Renaat Frans (UCLL), Erica Andreotti (UCLL)	Initial structure
29-05-2017	0.2	Renaat Frans (UCLL), Erica Andreotti (UCLL), Petros Stergiopoulos (EA) Manolis Chaniotakis (EA)	First full description ready to be read
08-06-2017	0.3	Renaat Frans (UCLL), Erica Andreotti (UCLL)	First version ready for further internal review
15-06-2017	0.4	Petros Stergiopoulos (EA), Manolis Chaniotakis(EA), Colette Laborde (CABRI)	Some remarks and additions
25-06-2017		Pierre Laborde (CABRI), Marcus Liwicki (UNIFRI), Robert Piechaud (IRCAM), Zoltan Karpati (LEOPOLY), Israel Fenor (WIRIS),	Cross-check of section 4 and 5 with the technical deliverables.
28-06-2017		Renaat Frans (UCLL), Erica Andreotti (UCLL)	All remarks processed, included the suggestions of Andrée Tiberghien on section 2 and 4. Preparation of final version
30-06-2017	1.0	Vassilis Katsouros (ATHENA)	Submission of deliverable to the EU

Disclaimer

iMuSciCA is an H2020 project funded by the European Union.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

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

1. Introduction

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

The iMuSciCA project will present therefore an interdisciplinary STEAM Pedagogy that connects different disciplines with each other on an inquiry and collaborative manner. It will bring new pedagogical methodologies in the classroom, with the use of state of the art educational technology tools. This way active, discovery-based, and more engaging learning can be facilitated, with opportunities for collaboration, co-creation and collective knowledge building.

2. Outline of the iMuSciCA STEAM Pedagogy

2.1. An interdisciplinary Pedagogy

The hallmark of STEAM education is that other aspects of education can be touched, more than is possible within single discipline teaching. This 'more' can be both on the content itself as well as on the context and approaches of learning (Honey et al., 2014 ; Quigley et al., 2017 ; Czerniak & Johnson, 2007).

Music, science and engineering practices all exist in their own right, they work all with their own language. Sometimes some polarization is seen between the integration of different disciplines on the one hand and the teaching within a single discipline on the other. As if one of the two would be the better choice (Tamassia & Frans, 2014 ; Lederman & Niess, 1997). The 2014 American report on STEM integration in K-12 education, formulates the following recommendation on this issue: "Designers of integrated STEM experiences need to attend to the learning goals and learning progressions in the individual STEM subjects so as not to inadvertently undermine student learning in those subjects." (Honey, 2014, p. 148). Stated otherwise: to make students see the connections, refinement of the disciplinary reasoning is not superfluous but needed. So the connection between the STEAM-fields does not go without the individual contributions.

Therefore the iMuSciCA STEAM pedagogy will address the different disciplines as they are: music, science/maths and engineering/technology. The STEAM pedagogy will let children play, discover and design within those disciplines.

But where is the 'more' then?

As STEAM is interdisciplinary, it uses the knowledge, processes and skills of different disciplines. The iMuSciCA STEAM pedagogy will connect those worlds explicitly. The more lies precisely there: in an awareness that STEAM can bring: only by discovering different aspects of the same, we can see more. The more you cannot see when you stay within one discipline. STEAM works on the transfer of

concepts and skills from one content area to another. It looks at the same in different ways and from different stances (Quigley et al., 2017 ; Frans et al., 2013).
For example, proportional reasoning is usually learnt in mathematics with numbers and geometrical figures. The concept of frequency of a sound played by a string provides a new field of experience of proportional reasoning.

STEM education initiatives need to build in opportunities
that **make STEM connections explicit to students and educators**
Recommendation 6 (Honey et al., 2014)

Therefore the iMuSciCA STEAM pedagogy will let students experience how 'more' can be discovered by the interplay of the STEAM-fields, more can be discovered if you learn to see through different 'glasses': the musical one, the scientific one and the engineering one. All those disciplines tell a piece of the 'whole'. The iMuSciCA learning environment will explicitly show how the same can be looked upon from different viewpoints: different background colours and symbols will be used per field (music, science/math, engineering/technology), so that the interdisciplinarity character will be made explicit to teachers and students (Lederman & Niess, 1997 ; Bartos & Lederman, 2014 ; Tamassia & Frans, 2014).

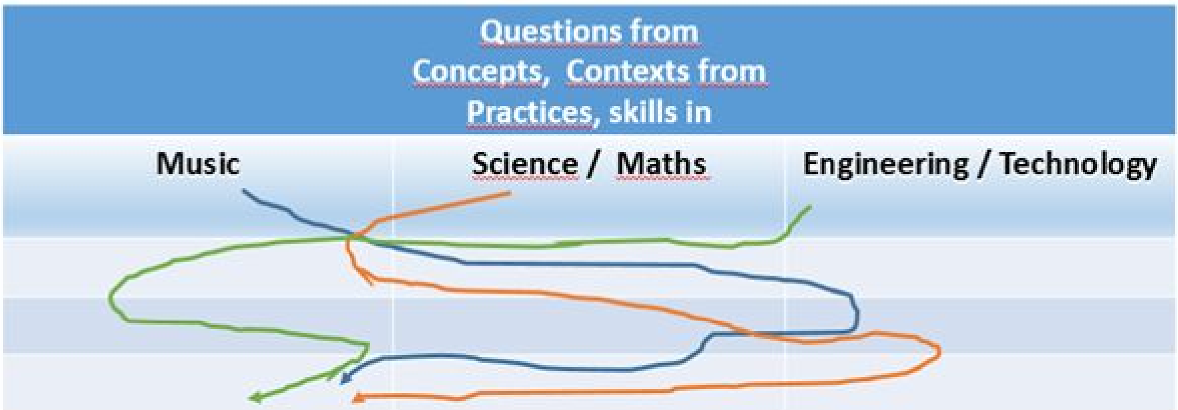


Fig. 1: The iMuSciCA STEAM pedagogy connects practices from three different STEAM-fields

The inclusion of concepts or practices from other subjects in iMuSciCA is intended to *deepen* the learning and the understanding of the targeted STEAM subjects. Deeper learning is opposed to superficial or 'thin' learning (Jensen, E., & Nickelsen, L., 2008). According to the Hewlett Foundation, deeper learning includes: (1) Mastery of core academic content (2) Critical thinking and problem-solving (3) Working collaboratively in groups (4) Communicating clearly and effectively (5)· Learning how to learn (6) Develop academic mindsets. See further on to the iMuSciCA deliverables "6.1 Pilot Testing Action Plan" and on "D2.2: Initial Evaluation metrics for deeper learning with iMuSciCA".

The hypothesis of the iMuSciCA project is furthermore that learners can play with these different viewpoints of STEAM, that these interdisciplinary views will free deep motivation by learners for the STEAM-world. This will also be assessed during the piloting.

So, in order to make connections between concepts, iMuSciCA will show the concepts of the different disciplines itself. Below you find the concept map of music components iMuSciCA will use. This concept map shows relation to concepts like melody, timbre, harmony, rhythm, etc. It can be used as a guideline both for teachers as well as to students, to orientate them from the shown musical components to the Science and Engineering fields onwards. So students discover that related concepts from different disciplines give a complementary view on the same phenomenon.

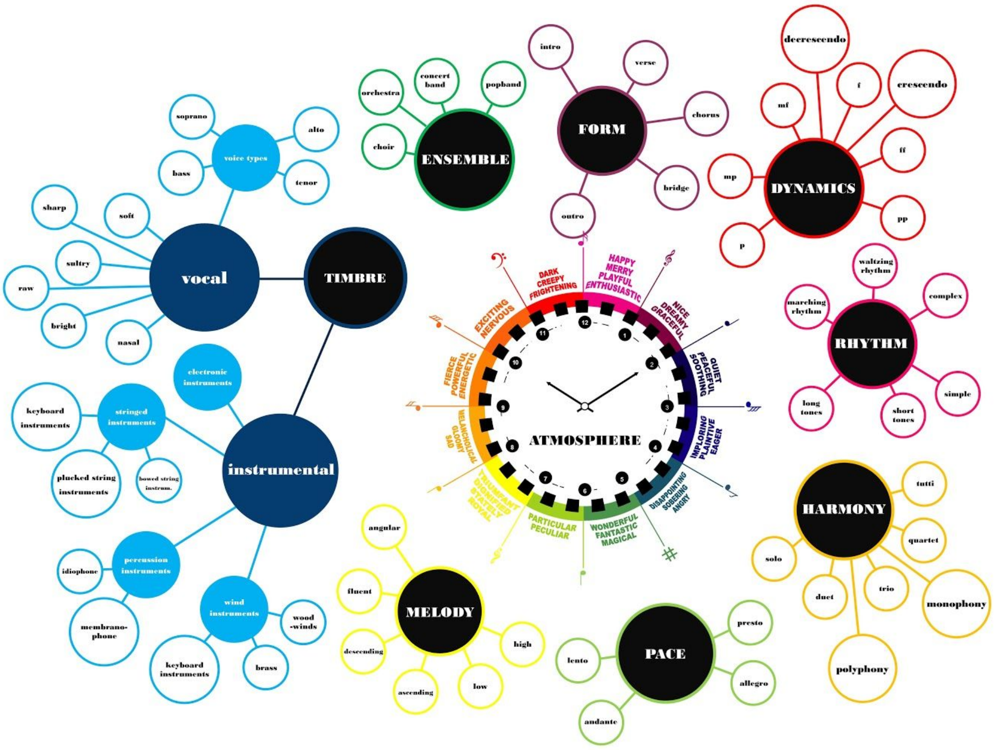


Figure 2. The iMuSciCA concept map of the components of music.

Below we will give an example where one can see how the interdisciplinary iMuSciCA STEAM pedagogy will work. In this example we will start from a musical experience or concept like the different timbres of different instruments. This concept is then viewed upon and investigated from a scientific point of view. So the same phenomenon is studied with different but complementary perspectives (music, physics, mathematics) and in this way possible relations or bridges between concepts are shown. This mechanism is at the heart of envisaged iMuSciCA STEAM pedagogy.

Example: **Timbre**

Let us take for instance the musical concept that different instruments have in general different timbre. One can hear for instance that a tone (like a central A/la) on a piano sounds different compared to the same tone on a violin. Both have the same pitch and if you measure the frequency you will get for both instruments 440 Hz for a central A/la (if the instruments are well tuned to the common scale). But still they sound different. You can differentiate the sound of the A/la from the piano compared to the sound of the same A/la but played on the violin. How is this possible if both sounds have the same frequency? Further investigations on this issue can lead them to a further hypothesis that a musical tone hardly ever sounds alone. There are other tones, overtones or partials that sound together with the so-called ground tone (fundamental tone). On the iMuSciCA workbench students can measure the overtones connected to a certain fundamental tone. Could it be that the difference between the same pitched tone on the piano compared to the one on the violin, lays in a difference in these *overtones*? Students can measure indeed the overtones of both instruments. They will find that the overtones between two instruments playing the same tone, share also the same overtones, with the same frequencies. But the strength or amplitude of these overtones differs indeed from a piano compared to a violin. Of course they try to verify this hypothesis with other instruments, etc.

2.2. An inquiry and collaborative pedagogy

IBSE stands for Inquiry Based Science Education. Inquiry-based learning is gaining popularity in the pedagogy of science at international level. Inquiry-based learning is typically organized in *inquiry phases* to form an *inquiry cycle*. In the literature different interpretations and inquiry models can be found (Pedaste et al.,2015).
For iMuSciCA we adopt a STEAM inquiry phases model which reflects the ideas of Deeper Learning (http://www.hewlett.org/strategy/deeper-learning/), but which is also applicable to the world of music (A) and technology-engineering (T-E) and not only phases that apply to science (S). Moreover the proposed STEAM Pedagogy and the phases are about **interdisciplinarity**, **inquiry** and **collaborative** learning. This is precisely what we see in the real STEAM world outside the classroom. In this sense the STEAM Pedagogy in the classroom reflects the STEAM world out there.

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, like for instance the making/design phase which can occur both in Technology-Engineering and Music. 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:

2.2.1. 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.

2.2.2. 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.

2.2.3. 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.

2.2.4. 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'. Built 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.

2.2.5. 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 nor 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.

3. TEAM Teaching for STEAM

3.1. Teachers reflect the STEAM pedagogy

The nature of STEAM as an interdisciplinary subject, uses the knowledge, processes and skills of different disciplines and connects them. That reflects exactly what we see in the real STEAM-world, outside the class. Out there, in the real STE(A)M world in research institutes, in companies etc., people from different backgrounds **collaborate** together in interdisciplinary teams, in order to understand or design a new 'whole'.

iMuSciCA STEAM Pedagogy

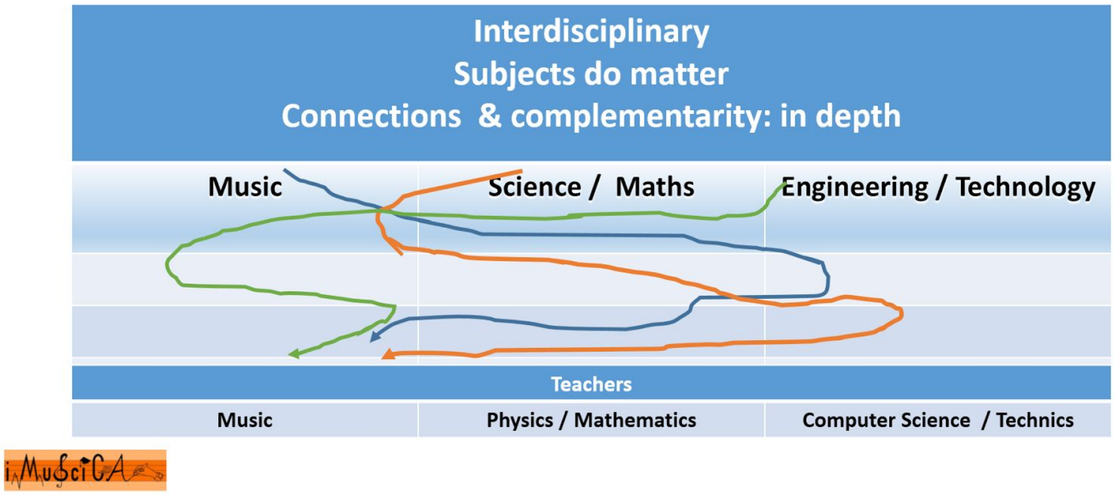


Fig. 3: In the real world of STE(A)M at universities, research institutions, in companies, etc. people from different background form interdisciplinary teams. That's exactly what the iMuSciCA pedagogy reflects in the classroom.

Nobody can study STEAM as a whole. STEAM can only be mastered by an interdisciplinary team. That's the case in the real world and in the school too. No teacher on his own can master STEAM. Bringing STEAM to classroom requires a team of teachers.

iMuSciCA TEAM Teachers for STEAM

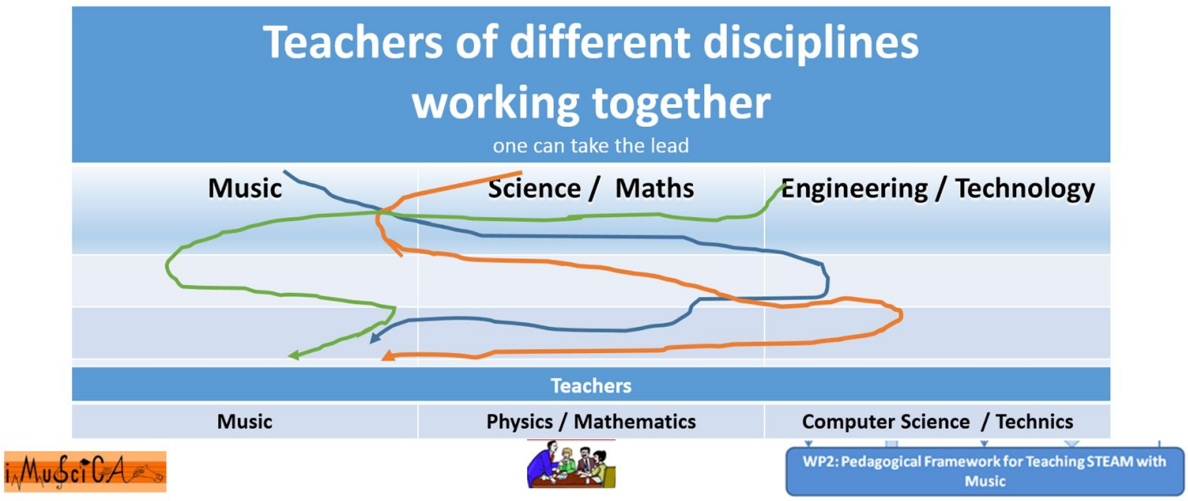


Figure 4. One teacher cannot master the broad STE(A)M fields. Therefore the iMuSciCA STEAM pedagogy needs a team of teachers from different backgrounds. This team of teachers reflects the diversity in the real world of STE(A)M

The iMuSciCA STEAM pedagogy will reflect this interdisciplinary nature of the STE(A)M world on a double dimension: (a) it will connect concepts and skills from different disciplines in order to look better to a whole (b) it recommends that teachers with different backgrounds (music, science/maths, engineering) work together to bring this STEAM pedagogy to the classroom.

3.2. iMuSciCA STEAM pedagogy: chances to connect to curricula in France, Belgium and Greece

In lots of schools worldwide, attention is given to integrated STEM and STEAM education. But joining science, technology, engineering, mathematics and art is far from evident also from the curriculum point of view. That’s why we investigate the possibilities in the current curriculum to introduce the iMuSciCA STEAM pedagogy in France, Greece and Belgium. We give some synthesis of the detailed study of the curricula.

3.2.1 In France

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

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

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

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

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

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

Conclusion for France:

The French curriculum of upper secondary gives somewhat less opportunities for iMuSciCA. The most important opportunities lie in the lower secondary (cycle 4 - 12 to 15 year-old students) Although, the context with music, science and technology, might be quite new there too, there are many chances where iMuSciCA can help realize the objectives of the curriculum and that of the newly implemented curricula reform. 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.

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

1. *Subject "Wetenschappelijk werk" – 3 hours/week*

   There is a context '*licht en geluid' Light and sound* where attention is given to
   - Vibration as source of sound
   - Sound propagate as a pressure wave through a medium

2. Subject "Muziek" – *1 hour/week* :

   Attention is given to :
   - Playing music: vocally, instrumentally, design music
   - Listen to sound and music
   - Music and sound as a form of human expression
   - Recognize musical instruments on the basis of timbre
   - Distinguish melody, rhythm, tempo and dynamics in music
   - Distinguish musical forms

- Musical notation in a graphical score of the pitch, dynamics, duration
- Use devices to play music or to record music
- Play music in group
- Music and the human body and music and technology

3. Subject "STEM":

   STEM – is a new subject in Flemish secondary schools; some hours/week depending on the school. No national curriculum: the school and teachers are free to develop a curriculum. iMuSciCA content can fit directly in this interdisciplinary subject.

<u>Belgium: Secondary school 2nd stage (15 -16 years-old):</u>

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.

<u>Belgium: Secondary school 3rd stage (17-18 years-old):</u>

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 set up, 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.

4. STEAM-learning on the iMuSciCA Workbench

4.1. Typical iMuSciCA interrelations made visible

As stated above, no one can claim 'to be (fully) STE(A)M'. We started from this reality to build an iMuSciCA STEAM pedagogy for schools: one that reflects the diverse world of STEAM. A pedagogy that teaches you how different disciplines work and how their practices interplay. So learning how STEAM works, can start from any STEAM component. But staying in one component isn’t an option either, it might only be a good starting point from where one learns to ‘talk' to the other disciplines. STEAM is about deepening your discipline and practicing the connection and application of your knowledge in other related fields. The iMuSciCA STEAM pedagogy shows you the different connections across music, science/math and engineering.

Regarding the nature of connections, iMuSciCA can connect a concept from one subject to a concept of another. For example, a mathematical model can show how altering the length of a string influences the height of a tone. So it connects a concept out of math/science to the height of an tone in music.

The iMuSciCA STEAM pedagogy may combine practices from two different fields, such as combining science inquiry (e.g. doing an experiment) with engineering design (in which data from a science experiment can be applied in the design of the instrument). For example, students learn how the tension of a string alters the height of the pitch. They will apply this knowledge when designing a monochord, including tuning screws on one end of each string allowing instrument tuning.

This previous example shows that, in order to see connections between concepts and practices in different field, students have to dive deep into concepts and practices of each field. That is why iMuSciCA pedagogy communicates explicitly the fields through which one is looking to the phenomenon and shows the different practices of the inquiry phases. This will be graphically implemented on the workbench by icons and colours.

4.2. Structure of scenarios, lesson plans and activities

The smallest building block of the iMuSciCA pedagogy is an activity. An activity is the smallest logical unit, part of a lesson. An activity is a particular task within a lesson to be followed by the students.
A set of activities form a lesson plan (typically takes 1-2h to be completed). Several lesson plans form a scenario (typically 4-8h). And several scenarios form a project (takes more than a month).

The iMuSciCA scenarios contain all the pedagogical phases of inquiry, whereas individual lesson plans can expand throughout one or more iMuSciCA inquiry phases. For instance:
Example of a project: *Create a virtual monochord*
This project could consist of following scenarios:

1. Scenario 1: Connecting sound with waves.
2. Scenario 2: Defining the parameters of interest and measuring them on real instruments
3. Scenario 3: Creating a virtual instrument.
4. Scenario 4: 3D printing the instrument.
5. Final product: a monochord

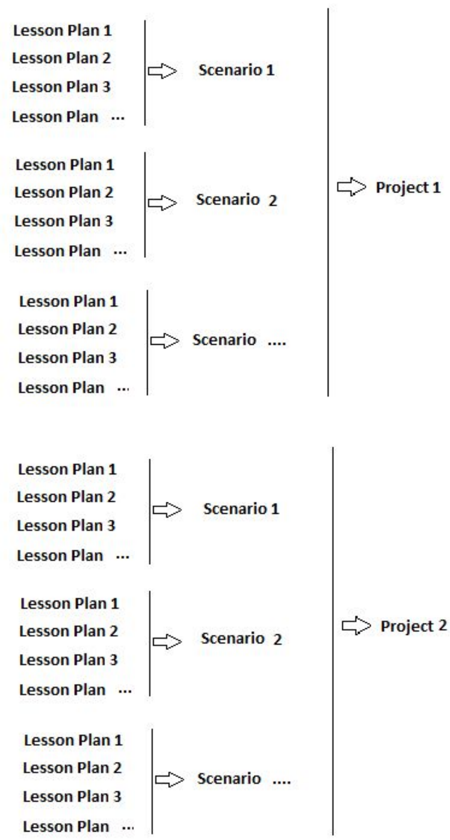


Fig. 5: Different lessons can form a scenario. Different scenarios can be part of a project.

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

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

4.3. Structure of iMuSciCA workbench reflects STEAM cases

We describe in general terms how the workbench will look like and why this is needed for STEAM activities.

4.3.1. Workbench

When one opens the iMuSciCA learning environment, there is a virtual desktop, called the workbench, where text, figures, videos, questions, assignments etc. can be displayed. It is a kind of an electronic textbook but with the possibilities of multimedia: interaction with figures, sounds can be played, embedded tools can be used.

4.3.2. STEAM fields

In line with the iMuSciCA STEAM pedagogy the student can see in which STEAM field he or she is in: a musical one, a scientific/mathematical one or an engineering/technological one. This could be made clear by using an icon and background colour, or alternatively with layers, so as to refer to, respectively, the STEAM fields of music, science/math or engineering/technology.

4.3.3. iMuSciCA STEAM inquiry phases

The same goes for the iMuSciCA STEAM inquiry phases: they are clearly communicated to the user. The five STEAM inquiry phases (1. Engage, 2. Imagine, 3. Create – Investigate/Design, 4. Analyze and 5. Communicate and Reflect) can for instance be represented by clear icons referring to them. By making this explicit, students become aware how these inquiries are slightly different in the different fields, but are connected at the same time.
This does not exclude that in a specific phase students can enter themselves in another subphase. For example, in an investigation/design phase some back and forth moves can occur between analysing local aspects and adjusting the design.

4.3.4. iMuSciCA Workbench Activity Environments

Around the iMuSciCA "desk" students find all kinds of tools: Music Tools, Science-Math Tools and Engineering-Technology Tools. In line with the STEAM pedagogy, they are more or less ordered regarding the STEAM-field they originate from. Depending on the lesson activity students are in, learning environment tools might be made visible or can stay hidden.

Under **Music Tools** one can find 3 boxes, one for each kind of musical instruments: a chordophone box, membranophone box and idiophone box. An aerophone box will be added at a later stage in the project, Also other Music tools like bows, plectrum, tuning machine etc. are available on the Music toolbar. Tools for musical expression are available too: pen-enabled tool for music creation, performance of and interaction with music by gesture recognition, performance sample sequencer.

To play with the instruments as a start, we choose two simple and fundamental ways for interaction:

- Pluck a string for chordophones on a standard way. The place where you pluck could be eventually taken into account (influence on the spectrum).
- Strike a membranophone with a human finger. The place where you tap could gradually be taken into account (influence on fundamental and spectrum).

Blowing through aerophones (open-end tube; closed-end tubes), will be added at a later stage, as to have an interaction for each of the three families.

On the **Science-Math Toolbar** you will find devices for frequency and spectrum measurements, visualisations of waveform, visualisations of harmonics, pen-enabled input of 'soundable' wave equations. These tools will be used in lessons and scenarios to deepen the concepts and the scientific understanding of the (different aspects of the) phenomenon music.

A typical activity here is investigating the change in the boundary conditions of instruments. Here you'll find a table describing the boundary conditions a user can change. The iMuSciCA environment lets the user hear and measure the effect of this altering on the frequency and on the spectrum of the sound:

String instruments	Membranophones	Aerophones[1]	Idiophones (Sounding bodies)
1. Alter **length** 2. Alter **tension** 3. Alter **thickness of strings** (in fact the *density per unit of length*) 4. Place where you pluck	1. Alter **surface** 2. Alter **tension** 3. Alter **thickness of material** (density per unit of length) 4. place where you tap	1. Alter **length** 2. Alter **diameter**	Bell to start with 1. Alter **mass** 2. Alter **diameter/ height** 3. Alter **geometrical form** 4. place where you tap
and listen how the pitch of a tune alters. Measure waveform, fundamental frequency and spectrum			

The **Engineering-Technology Tools** provide you with tools to build simple musical instruments that you can sound. The user can select elements for creating a virtual instrument from the three independent families: chordophones, membranophones, idiophones (and at a later stage also aerophones). The instruments are shown in 3D and the geometrical proportions can be altered.

Teachers and students can go through the three subject fields throughout their iMuSciCA experience: a layer-style/colour approach can support this 'many worlds' experience.

In the **Virtual Concert Hall** students can make music. Both *with virtual and real* instruments the performed music can be recorded to be heard again later.
In the iMuSciCA Virtual concert hall one can enter, play a previously recorded piece where one can play along with. It can be done by students from the same class but also by students from a different school, possibly from a different country. So there should be an "Ensemble-mode" that supports ensemble-play (because online simultaneous performance is technically hardly possible).

There is some **meta-information** available from each **recording**:
1. who made it,
2. was it played with a virtual instrument (which one? Can it be found? Indeed one can leave its virtual instrument in the concert hall),
3. was it a result of a iMuSciCA lesson or scenario (which one?)

[1] Will be considered at a later stage in the project.

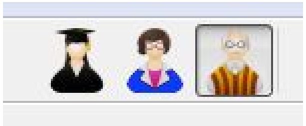
5. Typical iMuSciCA Use Case Scenario

5.1. Typical use scenario

5.1.1 The iMuSciCA workbench

We will describe here a typical way how a student and a teacher can use the iMuSciCA learning environment. In the iMuSciCA workbench there are two modes depending on the kind of user:

1. Student
2. Teacher



The interface changes 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 be able to *adapt the activity*.

Student mode

Typically (although not necessarily) a lesson starts in the musical world, from musical experiences, questions will rise here, so moving on to the scientific world is needed. Scientific questions and investigations let students discover more of what lays behind that musical experience. In technology, they will apply the scientific findings and apply the discovered mathematical model behind the phenomena. For instance, students will examine the properties of a virtual instrument and end up buildinging one with the desired properties. This virtual instrument can be brought into the virtual concert hall to perform with. Or (who knows) can be built for real. With these virtual and real instruments they can make music in the iMuSciCA Virtual Concert Hall (where the music can be recorded to be heard again). Of course also in the real classroom and school there can be some musical performance. So this typical scenario brings the students from the music world, into the science and engineering world and back to the musical world. But other pathways are possible too.

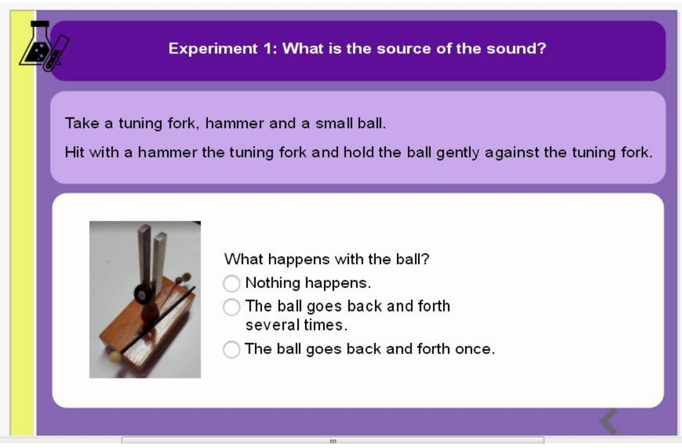


Fig. 6: A typical science experiment—in the "science world"—where the student investigates the propagation of sound

Teacher mode

To the extent that the author of the activity has made them available to the teacher, the teacher has to his/her disposal a subset of tools in order to adapt existing lessons by editing instructions, modify lesson parameters, changing tools made available for students.

5.1.2. Learning Content Authoring Tool

Using the Learning Content Authoring Tool an author is able to edit tools and objects of the learning environment in order to modify activities and lessons that will be used by students in the workbench.

5.1.3. The iMuSciCA Learning Content Management System

This environment allows to:

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

The author can:

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

The teacher can:

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

Teachers can adapt metadata after altering a lesson, scenario or project. These metadata are:

1. aimed age group
2. recommended time
3. language
4. learning objectives
5. STEAM fields addressed
6. STEAM inquiry phases addressed

The system t keeps metadata of every lesson plan, every scenario, every project:

1. aimed age group
2. recommended time
3. language
4. learning objectives
5. STEAM fields addressed
6. STEAM inquiry phases addressed

5.2. iMuSciCA technology creates learning environment for STEAM

To realise the above, we will build on the technologies created by the consortium. We give here a short overview of the technologies involved. Please refer for more details to the individual deliverables of work package 3 "Sub-systems specifications and overall architecture"(as indicated below):

1. **iMuSciCA Learning Environment**
   See D3.1 *User interaction with iMuSciCA workbench* and D3.3 *iMuSciCA workbench design and overall architecture*
2. **Learners' Activity Tracking**
   See D3.3 *iMuSciCA workbench design and overall architecture*
   Learning Content Authoring Tool, Learning Content Management System and Workbench
   See D3.1 *User interaction with iMuSciCA workbench* and D3.3 *iMuSciCA workbench design and overall architecture*
3. **Workbench Activity Environment: Virtual musical instrument Design**
   See D3.3 *iMuSciCA workbench design and overall architecture*, section 2.4.1
4. **Workbench Activity Environment: Pen enabled canvas for music co-creation**
   See D3.3 *iMuSciCA workbench design and overall architecture*, section 2.4.2
5. **Workbench Activity Environment: Pen-enabled Math Equation Generation for Music Creation**
   See D3.3 *iMuSciCA workbench design and overall architecture*, section 2.4.3
6. **Workbench Activity Environment: Performance/Interaction with Musical Instrument Using Gestures**
   See D3.3 *iMuSciCA workbench design and overall architecture*, section 2.4.4
7. **Workbench Activity Environment: Performance Sample Sequencer**
   See D3.3 *iMuSciCA workbench design and overall architecture*, section 2.4.5
8. **Workbench Activity Environment: Math (geometry, proportions, graphs of functions)**
   See D3.3 *iMuSciCA workbench design and overall architecture*, section 2.4.6
9. **Core-Enabling Technologies:**
   - 3D design tools: see D 3.2 *Technical Specifications for Adapting Core-Enabling Technologies*, section 3.1
   - Sound generation, Sound visualisation and analysis tools, actuation of physical object: see D 3.2 *Technical Specifications for Adapting Core-Enabling Technologies* section 3.2, 3.3, 3.4, 3.5, 3.6
   - Gesture interaction: see D 3.2 *Technical Specifications for Adapting Core-Enabling Technologies*, section 3.3.1
   - Pen-enabled music input and creation: D 3.2 *Technical Specifications for Adapting Core-Enabling Technologies,* section 3.4, 3.5

6. Conclusion

The iMuSciCA STEAM pedagogy presented here, foresees activities following different pathways across the different STEAM fields. The pedagogy implements adapted inquiry phases that show the own language and view of every field. The iMuSciCA STEAM pedagogy shows how these different views are complementary and connect in order to understand a common phenomenon.

iMuSciCA will work mainly with schools where teachers from different backgrounds cooperate. As such the pedagogy reflects the real STEAM world in research institutes and in companies where there are interdisciplinary teams too. Nobody can master STEAM as a whole. So also the teams of teachers as well as the collaborative teams of students in class reflect that complementarity.

As far as the connection to the existing curricula are concerned, the most promising possibilities are found in lower secondary education in France, Belgium and Greece, although higher up some other good opportunities can be found too.

In this deliverable we've sketched the first concrete outlines on how the iMuSciCA learning environment will look like: a central workbench around which tools of different STEAM fields can be found. These tools speak the 'local' language of concepts of the concerned field. It is precisely by understanding the 'world' they are in, that students can discover how each of these different fields helps to see the whole 'picture'. Also the different inquiry phases are adapted to the world they are in. Therefore students can learn to appreciate these different ways of thinking and above all, learn the connections between them. Crucial is that this interdisciplinary STEAM pedagogy will be made explicit to the iMuSciCA teachers as well (pedagogical guide).

The workbench will have a different 'behaviour' when used by a student, a teacher or an author. Students can perform assignments, lessons, scenarios, or can just experiment freely with the tools available. Teachers can adapt existing scenarios and lessons and adjust them more on their needs or - as authors - can can create full new lessons and scenarios.

References

[Bartos & Lederman, 2014]]Bartos, S. A., & Lederman, N. G. (2014). Teachers' knowledge structures for nature of science and scientific inquiry: Conceptions and classroom practice. Journal of Research in Science Teaching, 51(9), 1150-1184.

[Czerniak & Johnson, 2007]]Czerniak, C. M., & Johnson, C. C. (2007). *Interdisciplinary science teaching.* Handbook of research on science education, 537-559.

[Frans et al., 2013] Frans, R., Clijmans, L., De Smet, E., Poncelet, F., Tamassia, L., & Vyvey, K. (2013). *Vakdidactiek Natuurwetenschappen*.

[Honey et al., 2014] Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press

[Kim & Park, 2012a) Kim, Y., & Park, N. (2012). *Development and application of STEAM teaching model based on the Rube Goldberg's invention*. In Computer science and its applications (pp. 693–698). The Netherlands: Springer.

[Kim & Park, 2012b] Kim, Y., & Park, N. (2012). *The effect of STEAM education on elementary school student's creativity improvement*. In Computer applications for security, control and system engineering (pp. 115–121). Berlin Heidelberg: Springer.

[Lederman & Niess, 1997] Lederman, N. G., & Niess, M. L. (1997). *Editorial*. School science and Mathematics, 97(7), 341-344.

[Jensen & Nickelsen, 2008]]Jensen, E., & Nickelsen, L. (2008) *Deeper learning: 7 powerful strategies for in-depth and longer-lasting learning*. Corwin Press.

[Matthews, 1994] Matthews, M. R. (1994). *Science teaching: The role of history and philosophy of science*. Psychology Press.

[Pedaste et al., 2015] M. Pedaste, M. Mäeots, L.A. Siiman, T. de Jong, S.A.N. van Riesen, E.T. Kamp, C.C. Manoli, Z.C. Zacharia, E. Tsourlidaki, (2015) *Phases of inquiry-based learning: Definitions and the inquiry cycle,* Educational Research Review, 14, 47-61, 2015.

[Quigley et al., 2017] Quigley, C. F., Herro, D., & Jamil, F. M. (2017). *Developing a Conceptual Model of STEAM Teaching Practices*. School Science and Mathematics, 117(1-2), 1-12.

[Tamassia & Frans, 2014] Tamassia, L., & Frans, R. (2014) *Does integrated science education improve scientific literacy?* Journal of the European Teacher Education Network, 9, 131-141.

[Tiberghien, A., 2000] Tiberghien, A. (2000). *Designing teaching situations in the secondary school*. In R. Millar, J. Leach & J. Osborne (Eds.), Improving science education: The contribution of research (pp. 27-47). Buckingham, UK: Open University Press.

[Tsuprost et al., 2009] Tsupros, N., R. Kohler, and J. Hallinen.(2009). *STEM education in Southwestern Pennsylvania: Report of a project to identify the missing components*. Center for stem education and Leonard Gelfand center, Carnegie Mellon University

[Yackman, 2008] Yackman, G. (2008). "*STEAM education: An overview of creating a model of integrative education*," presented at the Pupils' Attitudes Toward Technology (PATT-19) Conference: Research on Technology, Innovation, Design & Engineering Teaching, Salt Lake City, Utah.