

European Science and Technology in Action Building  
Links with Industry, Schools and Home

*Work Package 3*  
**UNIT SOUND**  
**Teacher Information**



**European Science and Technology in Action:  
Building Links with Industry, Schools and Home**

**Lead partner for Unit:**

**C.M.A.**

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## A. Teacher Information

### ***I. Unit description***

The unit Sound is divided into 3 subunits, which can be used independently or sequentially. Each subunit can take different directions and emphasis depending on the curriculum and particular learning aims of the teacher.

The subunits 1 and 2 can also be used in a spiral type curriculum with subunit 1 focussed at an introductory level and subunit 2 at the higher stages of secondary school level.

The subunit 3 offers an extension for higher secondary school level and introduces students to the fascinating area of human speech.

The Sound unit is enriched with many ICT activities in which a sound sensor, an interface and software are used to record sound and to analyse the resulting sound waveforms.

#### **Subunit 1: Exploring sound**

In this subunit students study the basics of physics of sound. They learn that sound is caused by vibrations, and they explore how sound travels. They learn about the relationship of loudness and pitch to the amplitude and frequency of vibrations. They investigate the sounds of the human vocal cords. They also learn about the anatomy and functioning of the human ear and sound protection.

**Student level:** Lower secondary school level, students of age 11-15

**Discipline involved:** Physics

**Estimated duration:** 5-6 class periods

#### **Subunit 2: String instruments and wind instruments**

This subunit starts with an experiment of resonance in a model of a swing. Students can feel that a minor influence can give a great effect. Further on, students perform experiments with strings, including double bass, guitar and the Melde's experiment on standing waves. After experiments involving sound in air columns follow. At the end of this subunit, some open inquiries are described that students can choose from. The knowledge build in activities 1 to 7 is a good basis to start to work on each of the activities 9 – 11.

**Student level:** Higher secondary school level, students of age 15-17

**Discipline involved:** Physics

**Estimated duration:** 5-7 class periods and 2 class periods of independent working time

#### **Subunit 3: Human speech**

In this subunit students study the principles of human speech, speech analysis and synthesis. They learn fundamentals of human speech production, they record different sound signals and learn how to read and interpret a time signal and a spectrogram. They study how the human speech can be artificially produced.

**Student level:** Higher secondary school level, students of age 16-19.

**Discipline involved:** Biophysics (Physics, Biology).

**Estimated duration:** 3 class periods

## ***II. IBSE character***

### **Subunit 1**

To introduce a new subject like sound, the teacher should address the student's curiosity with questions involving both known, or seemingly known, concepts and unexpected holes in their understanding. This approach is therefore a form of the inquiry-based method of 'teaching by questioning'. The main problem here for most teachers is the delicate balance between not saying too much and not answering too soon while at the same time keeping track of time and not letting the students go astray into unrealistic and unprofitable directions. Having said that, it should be emphasized that not every scientifically unacceptable scenario or solution is necessarily unprofitable. A proposed explanation may at the one hand be incorrect but may at the other hand contain nice elements of scientific thinking and motivation to solve the problem.

Being introductory at an elementary level, the main IBSE approaches employed here are reflective discourse, interactive demonstration, guided discovery and guided inquiry. Through the activities in this subunit students develop basic abilities to do and understand scientific inquiry.

- Asking and answering questions.
- Planning and conducting simple investigations.
- Employing tools to gather data.
- Using data to construct reasonable explanations.
- Communicating investigations and explanations.
- Understanding that scientists use different kinds of investigations and tools to develop explanations using evidence and knowledge.

Some activities are ICT activities in which a computer with sound sensor is used to record sound waveforms.

### **Subunit 2**

The context of a guitar or other string instrument will trigger the student to do their own investigations. What knowledge is required to build a guitar? Which physical laws are there to keep in mind when building a guitar? To get to know this, students analyse the playing of a double bass and the frets on a guitar. The knowledge gathered in these activities is applied to the new context of air columns in wind instruments.

The main IBSE approach in this subunit are guided discovery and open inquiry.

Inquiry based skills developed in this unit are amongst others:

- Performing experiments.
- Analyzing results obtained with experiments (or presented by the teacher).
- Communicating results with the use of graphs.
- Using results from one experiment (double bass) to analyze the results of another experiment (frets of a guitar).
- Using knowledge from one field of acoustics (strings) in another field of acoustics (air columns).

In some activities the computer is used to record sound and to analyse the data.

### **Subunit 3**

The speech analysis and speech synthesis activities in this subunit are open inquiry assignments. In this activities students have to formulate their own research questions. This type of assignment is generally considered to be the highest level of inquiry-based learning. In these activities student develop many fundamental skills of inquiry-based science education like diagnosing problems, critiquing experiments, planning

investigations, searching for information, constructing models, debating with peers, forming coherent arguments.

Afterwards, students should express their understanding in a discussion with their peer students and the teacher, and or share their reports with another group for peer reviewing. In this way, they confront and share their preliminary (group) conclusions with others and come to final conclusions and explanations they construed themselves.

It is expected that students gain a deeper understanding of the phenomena in this approach and will probably remember the “new” knowledge longer through the process of internalization.

### **III. Science Content Knowledge**

#### **Subunit 1.**

In this subunit, students are not supposed to have any (formal) prior knowledge of the subject but some understanding of the concepts from their everyday life.

The activities in this subunit introduce students to the following concepts and ideas:

- Sounds are produced by vibrating objects and vibrating columns of air.
- Pitch and loudness are two characteristics of sound.
- Changing the way an object vibrates can change the pitch or volume of the sound produced
- Pitch is determined by the frequency and loudness by the amplitude of vibrations.
- Sound is produced by human vocal folds as air moves through the tightened folds.
- Sound requires a medium (for example, air, glass, metal, wood) to travel through.
- Speed of sound is less than the speed of light.
- The human ear has a membrane that vibrates when sound reaches it; the ear and the brain translate these vibrations into sensation of sound. Exposure to very loud sounds can cause damage to hearing.

#### **Subunit 2**

As pre-requisite knowledge, students are supposed to be familiar with the concepts: *wavelength, amplitude, frequency, period, sine function*. Of course these concepts should be repeated in this subunit but a basic understanding is required to build new knowledge.

The activities in this subunit introduce the students to the following concepts and ideas:

- Resonance
- Fundamental frequency
- Harmonics
- Standing waves
- Relation between the frequency and length of string/air column
- Timbre.

As a source for the teacher, the available physics courses should be appropriate. There are also numerous books that describe the relation between physics and music.

A recommended source, focusing on the physics of musical instruments is the book “Measured tones, the interplay of physics and music” by Ian Johnston (ISBN-10: 0750307625 ISBN-13: 978-0750307628).

**Subunit 3**

The activities in this subunit introduce students to the human speech production mechanism, human speech analysis and synthesis. The content is both about biology and physics. For biology students learn about the human vocal system and how the human speech is produced. In physics they create a model to describe how the human speech is produced, they analyse the human sounds and learn how human sounds can be created artificially.

As pre-requisite knowledge, students are supposed to know the concepts *frequency*, *amplitude*, *standing waves*, *resonance*, *fundamental frequency* and *harmonics*, and should be able to handle those both qualitatively and quantitatively.

Since this unit goes beyond a traditional school curriculum a model of human speech production is given as reading text for students in the Worksheet: Model of human speech production. The text is based on an article of Johan Sundberg "The acoustics of the singing voice", *Sci. Am.* **236**, 82 (March 1977).

Some useful resources;

1. Johan Sundberg "The acoustics of the singing voice", *Sci. Am.* **236**, 82 (March 1977) (see <http://www.zainea.com/voices.htm>)
2. Timothy Moran, "Application of sound spectrum analysis", *Phys. Teach.* **45**, 94 (2007)
3. Klaus Fellbaum, Jorg Richer, 'Human speech production based on a linear predictive vocoder', *ESCA/Socrate workshop on Method and Tool Innovations for Speech Science Education* (1999), see [http://www2.spsc.tugraz.at/add\\_material/courses/scl/vocoder/](http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/).

The Java simulation 'Model of the Human Speech Production' allowing sound analysis and synthesis is available at:

[http://www2.spsc.tugraz.at/add\\_material/courses/scl/vocoder/simulation.html](http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/simulation.html)

**IV. Pedagogical Content Knowledge**

General common students' difficulties identified by Science Education Research around Sound are:

- Sounds can be produced without using any material objects.
- Hitting an object harder changes the pitch of the sound produced.
- Loudness and pitch of sounds are the same things.
- The pitch of a tuning fork will change as it "slows down", (i.e. "runs" out of energy)
- Frequency is connected to loudness for all amplitudes.
- Human voice sounds are produced by a large number of vocal cords that all produce different sounds.
- Sounds can travel through empty space (a vacuum).
- Sounds cannot travel through liquids and solids.
- Sound moves faster in air than in solids (air is "thinner" and forms less of a barrier).
- Sound moves between particles of matter (in empty space) rather than matter.
- You can see and hear a distinct event at the same moment.
- Music is strictly an art form; it has nothing to do with science.
- In wind instruments, the instrument itself vibrates (not the internal air column).
- Sound waves are transverse waves (like water and light waves).
- Waves transport matter.

- Waves do not have energy.
- All waves travel the same way.
- Big waves travel faster than small waves in the same medium.
- When waves interact with a solid surface, the waves are destroyed.
- Ultrasounds are extremely loud sounds.
- Noise pollution is annoying, but it is essentially harmless.
- Sounds made by vehicles (like the whistle of a train) change as the vehicles move past the listener because something (like the train engineer) purposely changes the pitch of the sound.
- In actual telephones, sounds (rather than electrical impulses) are carried through the wires.

Students have to apply their knowledge in new situations and this might reveal misconceptions. The teacher should be aware of this, with asking questions to the student the teacher can make the student reflect on their pre-knowledge.

By giving answers or presenting data the students can work with, the character of the activity can become more closed. For example, without the graph or the demo on YouTube, the activity about harmonics in the subunit 2 is bounded inquiry. The question asked is '*in what ways might a string vibrate?*' and the students have to find their own way to answer this question. If students have enough prior knowledge and endurance, they are able to come up with the preferred answers. If not, the teacher has to decide how much he wants to help them (by doing a demo, presenting the graph or showing the YouTube movie).

An unpredictable variety of alternative or even misconceptions in the understanding of the content of the Human speech subunit is to be anticipated, as speech is such an everyday phenomenon that probably everyone has created his own model or mental picture of it. Special attention has to be devoted to common frequently felt obscurities like:

- *How can it be that the same vowel pronounced by different persons may sound completely different, yet one is able to recognise the vowel as such immediately?*
- *What are formants and in what way do they differ by age and gender?*
- *Is the recorded spectral sound-pattern reproducible and recognizable?*

It is here that the IBSE approach comes into play to provide a more tangible picture of the phenomenon of speech to the students. One may expect that the understanding achieved by own discoveries is less superficial and more concrete, as it is more linked to reality.

## ***V. Industrial Content Knowledge***

### **Subunit 1**

To start illustrating the relevance of sound to industry at this introductory stage, finding and mentioning professions (rather than the industries themselves) may be more effective. With sound the industrial applications are clear almost immediately f.i. through professions like musician, sound technician (TV broadcast), sound mixer (concert), audiometrist (selling hearing aids), audiologist (making audiograms), acoustic engineer, speech-trainer. For example an audiologist can be invited to visit the class during activities about sound hearing and sound protection to answer questions prepared by students. To engage students in technological design they could design and build their own simple models of the human eardrum or vocal cords.

## Subunit 2

There is a lot of physics involved in designing and producing musical instruments. For an existing instrument, one can make adjustments to change the sound of it. There are differences between guitars and students can do research on which instrument sounds better. How is *better* defined, can you do scientific measurements to find out which instrument is better? How well tuned is a guitar, what are the right positions for the frets on the fret board? What is meant with the *timbre* of an instrument? The basic knowledge to start answering these questions is implemented in the activities. In an open inquiry students will be able to answer (some of) the above questions.

Examples of industry links for activities in this subunit are:

- 2.1. Resonance – constructions of buildings or bridges;
- 2.2. Fundamental frequency; double bass – designing musical instruments;
- 2.3. Fundamental frequency; guitar – designing musical instruments;
- 2.4. Melde's experiment – constructions of buildings or bridges;
- 2.7. Standing waves in air, soprano saxophone – differences and similarities of wind instruments: clarinet, saxophone and oboe.

## Subunit 3

The first speech recognizer appeared in 1952 and consisted of a device for the recognition of single spoken digits. There are many domains for the commercial application of speech recognition for example:

- Health care – for converting voice-recorded reports as dictated by physicians and/or other healthcare professionals, into text format; medical analysis of voice problems.
- Military - speech recognizers have been operated successfully in fighter aircraft, with applications including: setting radio frequencies, commanding an autopilot system, setting steer-point coordinates and weapons release parameters, and controlling flight displays.
- Telephony - speech recognition is used mostly as a part of the user interface, for creating pre-defined or custom speech commands.

Scientists have attempted to simulate human speech since the late 1700s, when Wolfgang von Kempelen built a "speaking machine". By the 1970s digital computing enabled the first generation of modern teach-to-speech systems with fairly wide use.

Speech synthesis is now an assistive technology tool which use is significant and widespread. The use of it includes delivery of up-to-the-minute news, reading machines for handicapped, automotive voice controls and retrieving email over the phone – or any systems where the vocabulary is large, the content changes frequently or unpredictable, and a visual display isn't practical.

Speech synthesis techniques are also used in entertainment productions such as games and animations.

## VI. Learning paths

The topic of sound as outlined in this unit is made up of a series of subunits with a series of activities. Each subunit can take different directions and emphasis depending on the curriculum and particular learning aims of the teacher. The activities could be formulated in various different combinations to achieve the overall learning outcomes envisioned for the subunit. However in this section we outline one possibility of the order and flow of the activities.

**Subunit 1**

This subunit consists of 9 activities. The exemplary sequence of activities, in which all activities are used, is given in the table below sequence.

<b>Activity</b>	<b>Inquiry Type</b>	<b>E-emphasis</b>
1.1. Introduction to sound	Interactive discussion	Engagement
1.2. How sounds are made?	Guided inquiry	Engagement/Exploration/ Explanation//Elaborate
1.3. Make sound visible	Guided inquiry	Exploration/Explanation /Elaborate
1.4. Analysis of voice sounds	Guided discovery	Engagement/Exploration /Explanation
1.5. How sound travels?	Interactive demonstration/ Bounded inquiry	Engagement/Exploration /Explanation/Elaborate
1.6. How fast sound travel?	Guided discovery	Engagement/Exploration/ Explanation//Elaborate
1.7. Hearing sound	Guided inquiry	Explanation/Evaluate
1.8. How loud is too loud?	Guided inquiry	Explanation/Evaluate
1.9. What have you learned about sound	Interactive discussion	Elaborate/Evaluate

**Subunit 2**

In the table below, the activities are stated in the advised order. The activities 1-7 are mandatory and required to build the knowledge on sound. The activities 8, 9 and 10 are meant to test and evaluate the knowledge built in this subunit. These activities can be done independent from each another. Students can choose one or two activities and for instance present these to the rest of the class.

<b>Activity</b>	<b>Inquiry Type</b>	<b>E-emphasis</b>
2.1. Resonance	Guided discovery	Engagement
2.2. Fundamental frequency, double bass	Guided discovery	Exploration
2.3. Fundamental frequency, guitar	Guided inquiry	Explanation
2.4. Melde's experiment	Interactive demonstration	Extend/Exploration
2.5. Harmonics of the guitar	Bounded inquiry	Exploration/Evaluate



2.6. Standing waves in air; air column	Bounded inquiry	Evaluate
2.7. Standing waves in air; soprano saxophone	Guided inquiry -> Open inquiry	Elaborate
2.8. Timbre	Open inquiry	Elaborate/Evaluate
2.9. Beats	Open inquiry	Elaborate/Evaluate
2.10. Tuning the guitar	Bounded inquiry	Elaborate/Evaluate

### Subunit 3

This subunit consists of 5 activities. The following sequence of activities is recommended. Activities 4 and 5 are similar open-inquiry assignments. Half of the class could perform Activity 4 and half Activity 5.

<i>Activity</i>	<i>Inquiry Type</i>	<i>E-emphasis</i>
3.1. Sound graphs	Guided inquiry	Engagement
3.2. Model of human speech production	Interactive discussion	Exploration/Explanation
3.3. Sound signal analysis	Guided inquiry	Exploration/Explanation
3.4. Human speech analysis	Open inquiry	Extend/Elaborate
3.5. Human speech synthesis	Open inquiry	Extend/Elaborate

## VII. Assessment

### Subunit 1

Preferable, the students' assessment includes both a theoretical test (understanding basic concepts, understanding of sound waveforms) as a practical assignment.

### Subunit 2

The assessment might include both a theoretical test and a presentation about an experiment or literature research. These presentations can differ for the (groups of) students.

### Subunit 3

Preferably, the student's assessment includes both a theoretical test and a practical assignment. The theory of speech analysis may be tested as part of a school exam on waves and oscillations.

Students can write a report on the findings of their practical assignment (open inquiry activity) and present their results to the rest of the class. In addition, they share the data acquisition/analysis part in digital form.

## VIII. Student learning activities

### Subunit 1 – EXPLORING SOUND

#### Activity 1.1. Introduction to sound

##### Learning aims:

- Developing a concept map to realize the richness of sound as well in terms of physics as well in terms of everyday life
- Triggering student's' interest and curiosity about sound

##### Materials:

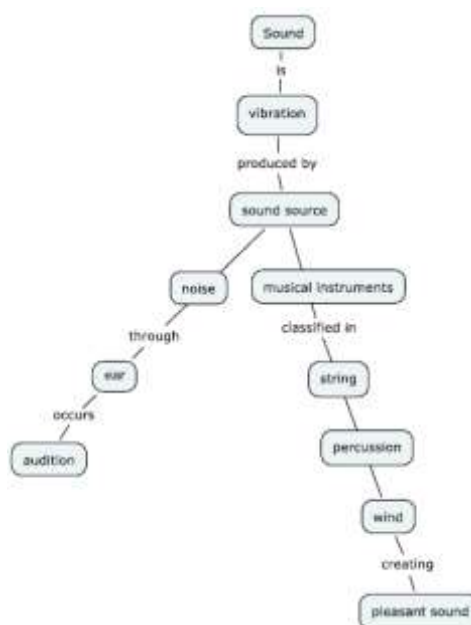
- Laptop/data projector, or Overhead projector/acetate, or Whiteboard/marker

##### Suggestions for use:

Let students shut their eyes and be still and silent for 3 minutes. Tell them to concentrate on what they hear. Have students open their eyes and list the sounds they heard.

Then, together with the students, develop a concept map to ascertain student's prior knowledge and to gain information regarding preconceptions students may have in relation to the topic of sound.

While doing this allow students to collectively give their opinions on what they know about sound, each time writing up the ideas onto the concept map. Try to group similar terms or ideas together so that by the end of the class discussion you have a concept map with a structure, which will relate to the series of lessons that you will teach on this topic. Allow students, as a group, to tell you all they know about sound. There may be some idea's missing from your concept map that you intend to cover in the lessons, or ideas that you feel students may have just forgotten about. Ask probing and guiding questions to get students to think about and come up with the ideas that relate to content but are missing in the concept map.



##### Possible questions:

- What do you know about sound?
- What makes a sound loud/soft?
- What was the loudest sound ever heard?
- What makes a sound pleasant/unpleasant?
- What makes a sound high/low?
- How do you think sound travels?
- How do we hear sounds?
- How do blind people use sounds "to see"?
- How do music and noise differ?
- How do musical instruments make their sounds?

<b>Activity 1.2. How sounds are made?</b>
<b>Learning aims:</b>
<ul style="list-style-type: none"> <li>• Understanding that sounds are produced by vibrations of objects or columns of air</li> <li>• Understanding that sound is a form of energy</li> </ul>
<b>Materials:</b>
<ul style="list-style-type: none"> <li>• An elastic ruler (metal, wooden), a rubber band, tuning fork, a drum, a pipe, other musical instruments e.g. guitar, violin, flute etc.</li> </ul>
<b>Suggestions for use:</b>
<p>Divide the class into small groups and hand out tuning forks, drums, rulers, and musical instruments. Ask students to produce sounds with given objects.</p> <p>Then hand out <i>Worksheet: How sounds are made? (Part I)</i> and let students do investigations. They have to answer a set of questions for each, investigated object. While the students are carrying out the investigations walk around the room asking each group questions to probe student's understanding. Once they have completed their investigations discuss with them: - how sounds are produced (providing energy), - what is the object doing as it produces the sound (vibrating), - how long does the sound last (as long as the object vibrates), - how the sound can be stopped (by "damping" vibrations), - how to change the properties of the sound (e.g. by changing the characteristics of the vibrating object).</p> <p>Hand out <i>Worksheet: How sounds are made? (Part II)</i>. Let students identify what vibrates to make the sound of instruments showed on the pictures. Ask them to come up with other examples of creating sounds.</p>
<b>Possible questions:</b>
<ul style="list-style-type: none"> <li>• How does the object produce sound?</li> <li>• How energy was provided to the object to produce the sound?</li> <li>• What is the object doing as it produces the sound?</li> <li>• How long does the sound last?</li> <li>• How can you stop the sound?</li> <li>• How can you make the sound higher or lower and softer or louder?</li> <li>• Do you see the ends of the tuning fork vibrating? Why or why not?</li> <li>• How sound is produced by an organ pipe or flute? What vibrates there?</li> <li>• How sound is produced by a guitar or violin? What vibrates there?</li> </ul>

<b>Activity 1.3. Make sound visible</b>
<b>Learning aims:</b>
<ul style="list-style-type: none"> <li>• Learning how to record sound with a sound sensor</li> <li>• Interpreting the recorded sound waveform graphs</li> <li>• Understanding that the sound signal is changing periodically</li> <li>• Introducing concepts of frequency, pitch and loudness</li> <li>• Exploring how the sound waveform is changing by changing loudness and pitch</li> </ul>

<b>Materials:</b>
<ul style="list-style-type: none"> <li>• A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6)</li> </ul>
<b>Suggestions for use:</b>
<p>Start the activity by asking students: 'What do you think a sound would look like if we could see it?' Have student volunteers come up to the board to illustrate.</p> <p>Divide the class into groups, hand out <i>Worksheet: Make sound visible (Part I)</i> and let students do their own investigations with a sound sensor and tuning forks. If needed, help students to set up the experiment and perform measurements with the computer.</p> <p>Hand out <i>Worksheet: Make sound visible (Part II)</i>, discuss the recorded sound waveform and let students calculate the frequency of the recorded sound signal. Then let them perform Investigation 1 and 2 and summarize their findings by defining the properties of sound: loudness (defined by sound amplitude), pitch (defined by sound frequency).</p>
<b>Possible questions:</b>
<ul style="list-style-type: none"> <li>• How sounds can be made visible?</li> <li>• What is the frequency of vibrations?</li> <li>• Determine the frequencies of the tuning forks used in your experiments? How did you figure this out?</li> <li>• Can you notice any relationship between the tuning forks appearance and the sound they produce?</li> <li>• What determines pitch?</li> <li>• What determines loudness?</li> </ul>

<b>Activity 1.4. Analysis of voice sounds</b>
<b>Learning aims:</b>
<ul style="list-style-type: none"> <li>• Understanding that the vibration of vocal cords creates our voice</li> <li>• Interpreting sound waveforms of a variety of voice sounds</li> <li>• Understanding differences between sound waveforms of different voice sounds</li> </ul>
<b>Materials:</b>
<ul style="list-style-type: none"> <li>• A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6)</li> </ul>
<b>Suggestions for use:</b>
<p>Divide the class into small groups, hand out <i>Worksheet: Analysis of voice sounds (Part 1)</i> and let students do activities described under Observation and Investigation. Then discuss with them how voice sounds are made.</p> <p>Then divide students to work with computers, hand out <i>Worksheet: Analysis of voice sounds (Part II)</i>. Let them do their own investigations with a sound sensor. If needed help students to set up the experiment and perform measurements with the computer.</p> <p>Once students have completed their investigations summarize the results of their investigation by discussing the results of their experiments.</p>

## Possible questions:

- How voice sounds are made?
- How the vocal cords work?
- What is the difference in waveforms of tuning fork and voice sounds?
- What is the difference in waveforms of different vowels?

**Activity 1.5. How sound travels?**

## Learning aims:

- Recognising that the sound needs a medium to travel
- Understanding that sound travels through different mediums, including solids, liquids, and gases

## Materials:

- Sound source, bell jar, vacuum, a string telephone, balloon with water, water, different medium for example wood, metal, glass, plastic, ceramic etc.

## Suggestions for use:

Hand out *Worksheet: How sounds travel (Part I)*, let students read and answer questions.

Then show them the following demonstrations:

1. Place five coins, in a line next to each other, flat on the table. Flick a sixth coin so that it hits the first coin in the line. Last coin in the line will move.
2. Place an alarm clock or an electric bell in a large bottle. Let the bell ring in air. Then pump the air out of the bottle and let the bell ring in a vacuum.
3. Place a candle in front of a speaker. Turn on the speaker (frequency 5 – 10 Hz). The flame flickers indicating air movement. (Instead of the demonstration the included video can be displayed).
4. Use a coiled spring (slinky); send pushes and pulls along the spring.



Discuss with students their observations and help them to construct the following ideas:

1. Energy can be transmitted through the particle of a substance.
2. Sound needs a medium to travel through; it cannot be transmitted in the absence of particles.
3. Sounds waves are alternate compressions and expansions caused by the back-forth motion of the particles of a medium.

Divide the class into groups and hand out *Worksheet: How sounds travel (Part II)*. Give each group a sound source and materials to investigate. These can be two cans (or paper cups) connected with a string, a balloon with water, book, and different medium like wood, metal, glass, plastic, ceramic, etc. In this activity students are asked to design their own investigation to find out if sound can travel through different materials and through which material(s) sound travels the best. Walk around and give students some tips if necessary. Ask them about the designs of their (fair) investigations.

Finally let each group present their conclusions, allow students to debate their reasoning.

**Possible questions:**

- How sound energy is transmitted?
- Why can you not hear the bell ringing in the jar?
- Can you hear the sound from a sound source when it is held in the air?
- What medium was the sound travelling through in this case?
- Does sound travel through string?
- Can you hear your partner better when the string is wet or dry?
- Does sound travel through glass? Wood? Etc?
- Do sounds get weaker with distance?

**Activity 1.6. How fast sound travels?****Learning aims:**

- Understanding the speed of sound is lower than the speed of light
- Determining the speed of sound in air by using the echo method
- Understanding that the speed of sound depends on the medium

**Materials:**

- A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6), 1-m long cardboard or plastic tube

**Suggestions for use:**

Show a video clip of lightening in the sky. Hand out *Worksheet: How fast sound travels? (Part I)* and ask students to answer question 1. Discuss with students why we see the light before we hear the sound.

Then divide students into groups to work with computers. Hand out *Worksheet: How fast sound travels? (Part II)* and let students perform computer measurements to determine the speed of sound in air. If needed help students to set up the experiment and perform measurements with the computer.

Once students have completed their investigations compare the sound speed values determined by students with the theoretical value. Here you can also discuss more examples of the use of echoes (ships navigation, animals using “echolocation” etc.)

Let students find out the speed of sound in other materials. Discuss whether sound travels better in liquids, gases, or solids?

**Possible questions:**

- Why do you see lightning before you hear thunder?
- What is the measurement method used to calculate the speed of sound in air?
- How do you calculate the speed?
- What do you think can influence the speed of sound?
- In which materials the speed of sound is the highest?
- In which materials the speed of sound is the lowest?

<b>Activity 1.7. Hearing sound</b>
<b>Learning aims:</b>
<ul style="list-style-type: none"> <li>• Understanding that the ear detects sound vibrations</li> <li>• Understanding how the human ear works</li> <li>• Understanding that human hearing range lays between 20 and 20000 vibrations per second</li> </ul>
<b>Materials:</b>
<ul style="list-style-type: none"> <li>• A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6), a model of the human ear</li> </ul>
<b>Suggestions for use:</b>
<p>Hand out <i>Worksheet: Hearing sound</i> and let students read and answer questions 1 to 3. Then discuss how the human ear works. To visualize it you can use an animation, for example: <a href="http://www.sciencekids.co.nz/videos/humanbody/ear.html">http://www.sciencekids.co.nz/videos/humanbody/ear.html</a>.</p> <p>There is a possibility for cross-curricular links here. It would be a good opportunity to link to the biology topic of the ear.</p> <p>Here students also could be engaged in technological design as they could design and build their own simple models of the human eardrum.</p> <p>As the last activity let students read question 4. Start a discussion about what they can hear and what they cannot hear – and lead onto hearing ranges of humans and animals.</p>
<b>Possible questions:</b>
<ul style="list-style-type: none"> <li>• When a compression in a sound wave in the air hits the eardrum, in which direction does the eardrum move?</li> <li>• In which direction does the eardrum moves when an expansion of a sound wave arises?</li> <li>• If you hear a bird sing with a frequency of 2000 vibrations per second, how many times per second does the eardrum vibrates?</li> <li>• How does the ear response to a loud sound differ from its response to a soft sound?</li> <li>• How does the ear response to a high sound differ from its response to a low sound?</li> <li>• Why sounds aren't as loud when you cover your ear?</li> <li>• How does the ear strengthen the sound waves so that they will be strong enough to affect the liquid of the inner ear?</li> <li>• Why you do not hear a dog whistle while your dog does?</li> </ul>

<b>Activity 1.8. How loud is too loud?</b>
<b>Learning aims:</b>
<ul style="list-style-type: none"> <li>• Understanding that sound intensity (loudness) is measured in decibels</li> <li>• Understanding that exposure to very loud sounds can cause damage to hearing</li> </ul>
<b>Materials:</b>
<ul style="list-style-type: none"> <li>• A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6), a sound source, a shoe box, different isolation materials like cotton wool,</li> </ul>

fabrics, egg boxes, foam, newspaper, etc.

### Suggestions for use:

Divide the class into small groups to work with computers, hand out *Worksheet: Sound protection (Part I)*. Let students perform computer investigations to determine the sound intensity of different sound sources and to determine the best sound insulator. Once students completed their investigations discuss their results.

Then hand out *Worksheet: Sound protection (Part II)*. Have students research the effects of sound on their health (Research assignment: How loud is too loud?). In their investigation they can use a nice interactive animation – ‘Interactive sound ruler’ available via <http://www.nidcd.nih.gov/health/education/decibel/decibel.asp>.

Then use protective earmuffs to show students and have a class discussion on why different professions might need to use these, and what would be the effects for these people if the ear protection is not worn. Discuss the possible damages loud sounds can have on human hearing.

This lesson would be an excellent time to invite an audiologist to visit the class. Have students write questions for the speaker on slips beforehand. In this students should be encouraged to relate their question with the research assignment.

### Possible questions:

- Why do you think construction workers wear earmuffs?
- Can you think of any other profession who need to wear ear protection?
- What might happen if these people don't wear ear protection?
- Which material is the best at stopping sound?
- Which material is useless at stopping sound?
- Does the twice the thickness of the material stop the sounds any better?

## Activity 1.9. What have you learned about sound?

### Learning aims:

- Elaborating concepts learned throughout the subunit

### Materials:

- Whiteboard/marker, or Laptop/data projector, or Overhead projector/acetate

### Suggestions for use:

Use the concept map generated in the first activity to have an interactive group discussion on what students have learned about sound. Students need to revisit their original ideas. The final concept map should show a schematic summary what was learned.



## Subunit 2 – SOUND IN STRING INSTRUMENTS AND WIND INSTRUMENTS

### Activity 2.1. Resonance

#### Learning aims:

- Recapture prior knowledge about oscillations
- Trigger curiosity about resonance
- Realize that small forces can cause a huge effect
- Introduce the concepts of resonance and natural frequency

#### Materials:

- Heavy object (approx. 5 kg – 10 kg) and double rope (to stabilize the motion)

#### Suggestions for use:

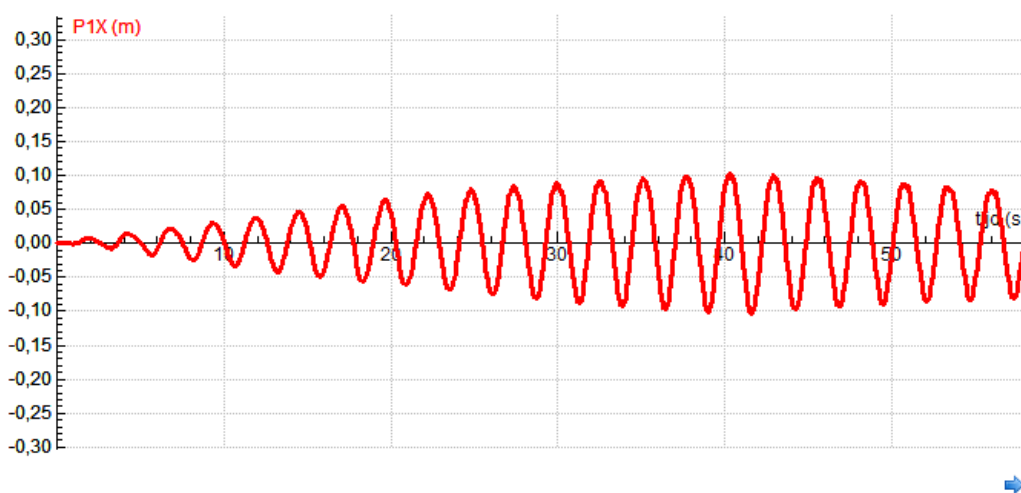
In this activity students try to get a heavy object to oscillate by blowing and answer the question: how can it be that such a small force results in such strong effect?

See for a demonstration of this experiment: <http://youtu.be/zqhF7NEOSY>

It should be enough to do this experiment two or three times, with different teams of two-three students. Try to see how the students work together and check if the team that has a student on each side of the swinging object gets larger amplitude.

This experiment is also available as Coach data video activity. Students that are not able to do the experiment might want to work with this activity.

The figure below shows the graph of a heavy bag oscillating (5 kg). A graph like this might be used as a basis for assessment questions. If students are familiar with the theory (and the relation between length of the rope and the frequency), they might want to calculate the length of the ropes used.



*Position of the heavy object oscillating.  
The measurement lasts 60 s, one can see that the blowing stops around  $t = 40$  s.*

Another way to determine the frequency of the movement is by analysing the sound file of the YouTube movie. Every blow is easy to recognize and since the blows are in the right frequency, the frequency of the vibration can be derived from this sound file.



*The sound file of the movie of this experiment.  
Each blow is easy to recognize on the sound track. Between  $t = 18$  s and  $t = 56$  s, there are 16 blows. This means a frequency of  $16 / 38 = 0.42$  Hz (or  $T = 2.38$  s).*

Another example of resonance might be the Chladni experiment:

<http://www.youtube.com/watch?v=Zkox6niJ1Wc>. See for more information:

<http://hyperphysics.phy-astr.gsu.edu/hbase/sound/reson.html#resdef> or

<http://en.wikipedia.org/wiki/Resonance>

### Possible questions:

- How can it be that such a small force causes such a strong effect?
- Define the influence of the mass, rope length and amplitude on the frequency of oscillations (recapturing prior knowledge).
- Based on the graph of the position of the object one can ask how many blows were given.
- Determine amplitude and frequency of the oscillation based on the graph at a certain moment.
- Check if the amplitude has any influence on the frequency.
- One can calculate the energy of the object (mass is 5 kg) and thus calculate how much energy is transported with each blow.
- As an application of the theory, one can calculate the length of the ropes based on the frequency of the oscillation.

## Activity 2.2. Fundamental frequency, double bass

### Learning aims:

- Determine qualitatively relation between string length and its fundamental frequency
- Discover that only certain lengths of the string are used when playing music

### Materials:

- Pen and paper
- Coach 6 file with original data

### Suggestions for use:

In this activity students analyse positions where a bass player places his fingers during playing different notes. The students use the graph to answer the given questions. During the activity they get a better understanding of what is showed in the graph.

The questions 1 to 4 are easy to answer for most students. Question 5 goes a little deeper and requires some calculations. It is up to the teacher to decide how much help is needed

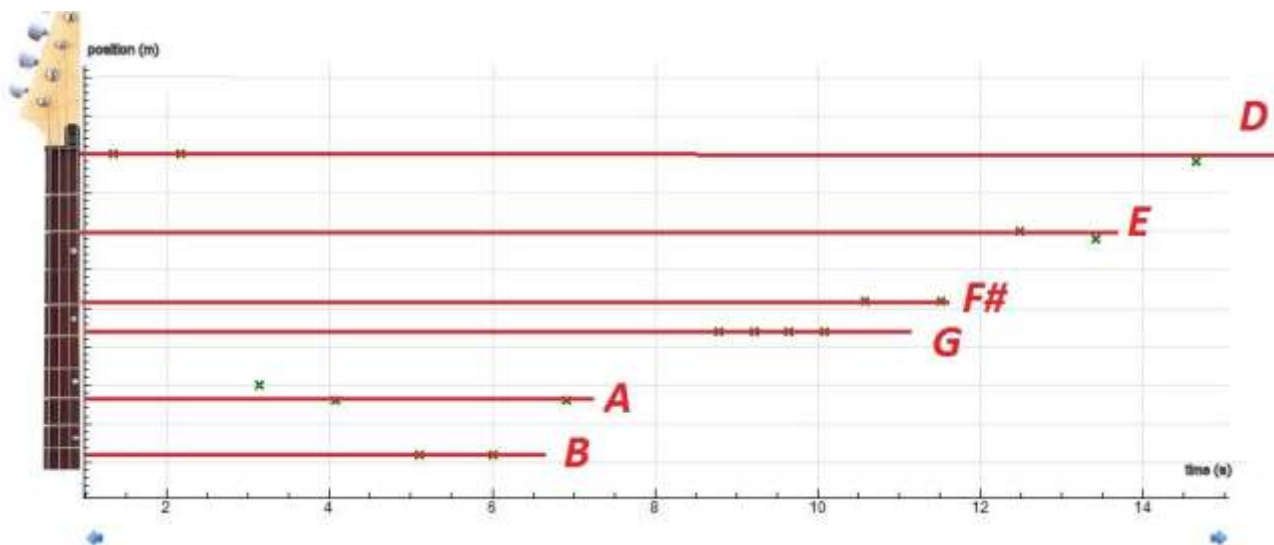
here.

Depending on the spirit in the class and the skills in music, the teacher can decide how much time is spend on question 6 (let the students guess which tune is played). Even make a contest out of it (be sure to remove the link to the answer in the worksheet) or let the students draw a graph for another simple tune.

Answers to the questions in the worksheet:

There are six different notes played (question 1) and the first time the A is played, the finger is a bit too high (question 2). When the finger is too high, the string is too long and the tone is too low (question 3). The semitone (question 4) between F# and G is also clear from this picture.

In the picture below the graph of position of the finger of the bass player against time is combined with a picture of a guitar. The positions match the positions of frets of the guitar. The names of the tones played are also indicated.



Question 5:

Going from the first notes (D) to the third note played (an A at  $t = 2$  s) the frequency is multiplied by 1.5. This means that the remaining length of the string is 66,7 % of the original length. Thus, a difference of 33,3 % of string length is 32 cm (90-58). This means that the string has a length of 96 cm.

In reality this length is a bit more, the data are a bit disturbed because the bass is moved during the video recording. However, the differences between theory and measurement are not that big (less than 10%).

#### Possible questions:

- Which are the lengths used on double bass? Is this comparable to other stringed instruments like guitar?
- Explain if a graph like this would be different for a guitar or violin.
- Make a similar for another simple tune (a suitable question for students with a bit of experience in music).
- Compare the graph in the worksheet with a tablature for guitar or bass (see for example <http://www.bassmasta.net/charts.php?chan=popular-bass-tabs> or <http://www.ultimate-guitar.com/top/top100.htm> )

### Activity 2.3. Fundamental frequency, guitar

#### Learning aims:

- Determine relation between fundamental frequency  $f$  of the string and its string length  $L$ .

#### Materials:

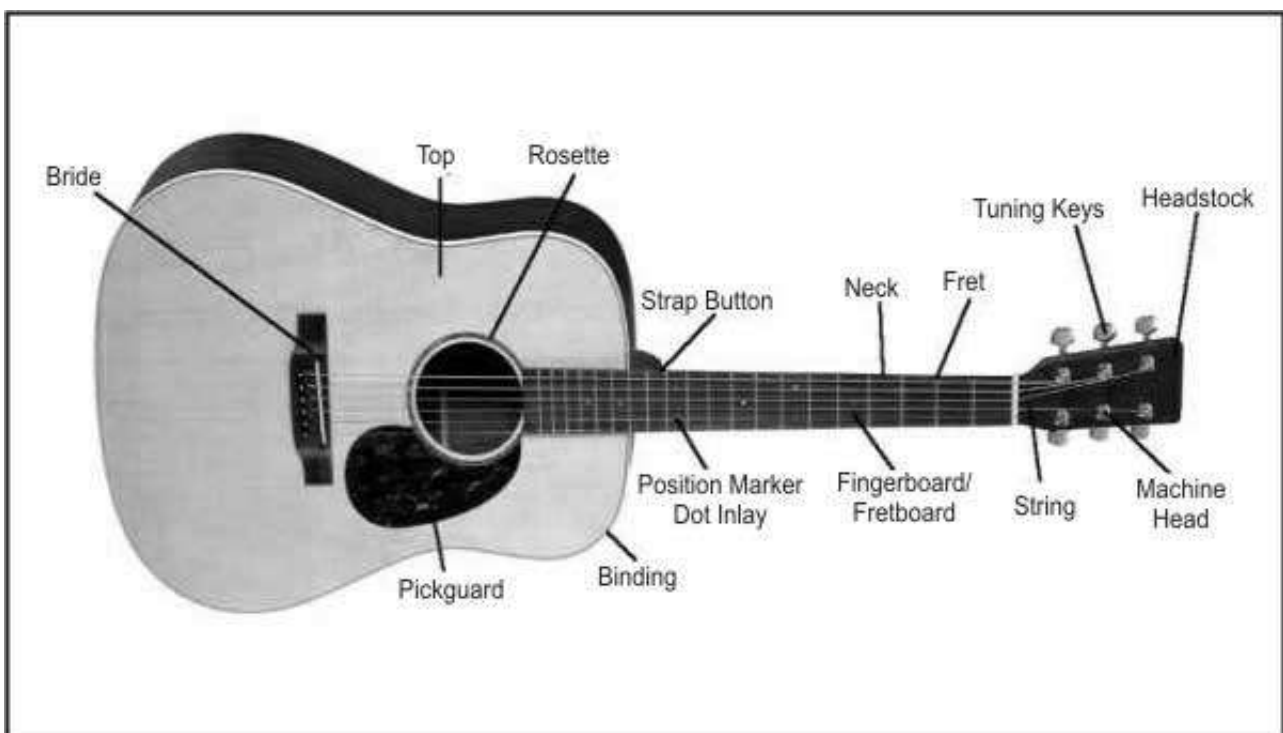
- Guitar
- Measuring ruler
- A computer with a sound sensor and Sound analysis program.

#### Suggestions for use:

In this activity students measure the length of the string shorted by using guitar frets and the corresponding natural frequency of the shorted string. Based on the measurements they determine the relation between the natural frequency of the string and its length ( $f \approx 1/L$ ).

It is highly recommended to do measurements with a real guitar and to have one guitar for 3 or 4 students. Try to get some guitars from the music teacher or let the students bring their own guitar. A bass guitar or any other fretted instrument (ukulele, banjo, mandolin) will do as well.

It also might be useful to know some parts of the guitar by name, see the picture below.



If there is no guitar available, the following data can be used:



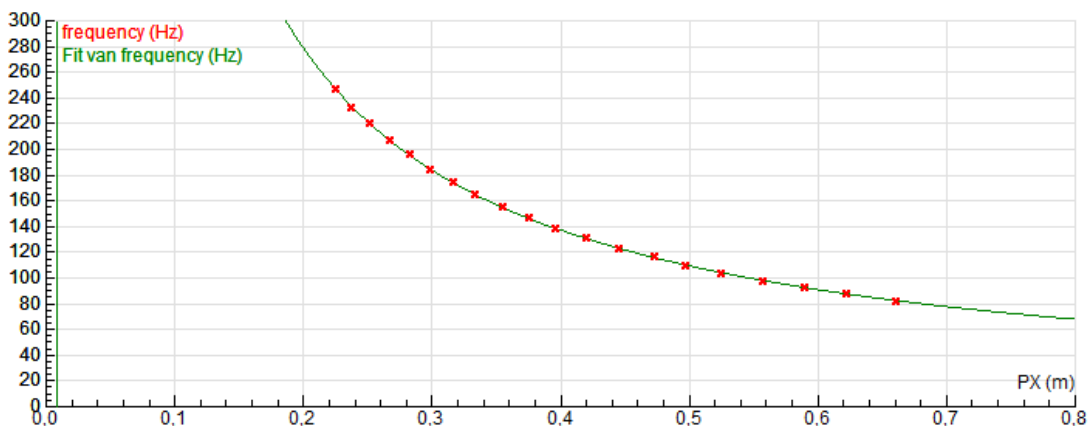
or other data can be found on the internet:

<http://entertainment.howstuffworks.com/guitar3.htm> or

<http://www.physics247.com/physics-tutorial/guitar-string-harmonics.shtml>

Hand out the Worksheet: Fundamental frequency, guitar.

Let the students do their measurements and check these data during the measurements. There might be small differences between the different types of guitar but in general the values measured will be similar. The diagrams should all have the same shape, similar to the one showed below.



The relation between  $f$  and  $L$  is  $f = v/2L$ . Here,  $f$  is frequency in Hertz,  $v$  is the wave speed in a certain string,  $L$  is the length of the string that is able to vibrate.

Besides this measurement, students might want to check the ratio between two string lengths with just one fret between them. If we define the length from the string, measured from the bridge to the  $n$ -th fret as  $L_n$ , then the ratio  $L_n / L_{n+1}$  is a constant.

This is supposed to be  $L_n / L_{n+1} = 1.06$  (start to number  $n$  at the machine head).

There is a lot of material about the physics of a guitar available on the internet. You might want to check these sources:

<http://www.physics247.com/physics-tutorial/guitar-string-harmonics.shtml>

<http://www.cs.helsinki.fi/u/wikla/mus/Calcs/wwwscalculator.html>

Teachers who have access to Physics Teacher Online might want to read 'Experimenting with Guitar Strings' by Michael C. LoPresto:

[http://tpt.aapt.org/resource/1/phteah/v44/i8/p509\\_s1?isAuthorized=no](http://tpt.aapt.org/resource/1/phteah/v44/i8/p509_s1?isAuthorized=no)

#### Possible questions:

- Does the relation  $f = v/2L$  corresponds with the information given in the previous activity about the bass string (if frequency is multiplied by 1.5 than the string length is divided by 1.5)?
- What do you think how your resulting graph would look like if the tension of the string would be higher?
- What do you think how your resulting graph would look like if the string would be thicker?
- What do you think what the effect will be for the frequency if the temperature is higher or lower?
- Why has a guitar six strings?

### Activity 2.4. Melde's experiment

#### Learning aims:

- Study the relation between the frequencies and standing waves in a vibrating string
- Understanding concept of fundamental frequency and harmonics

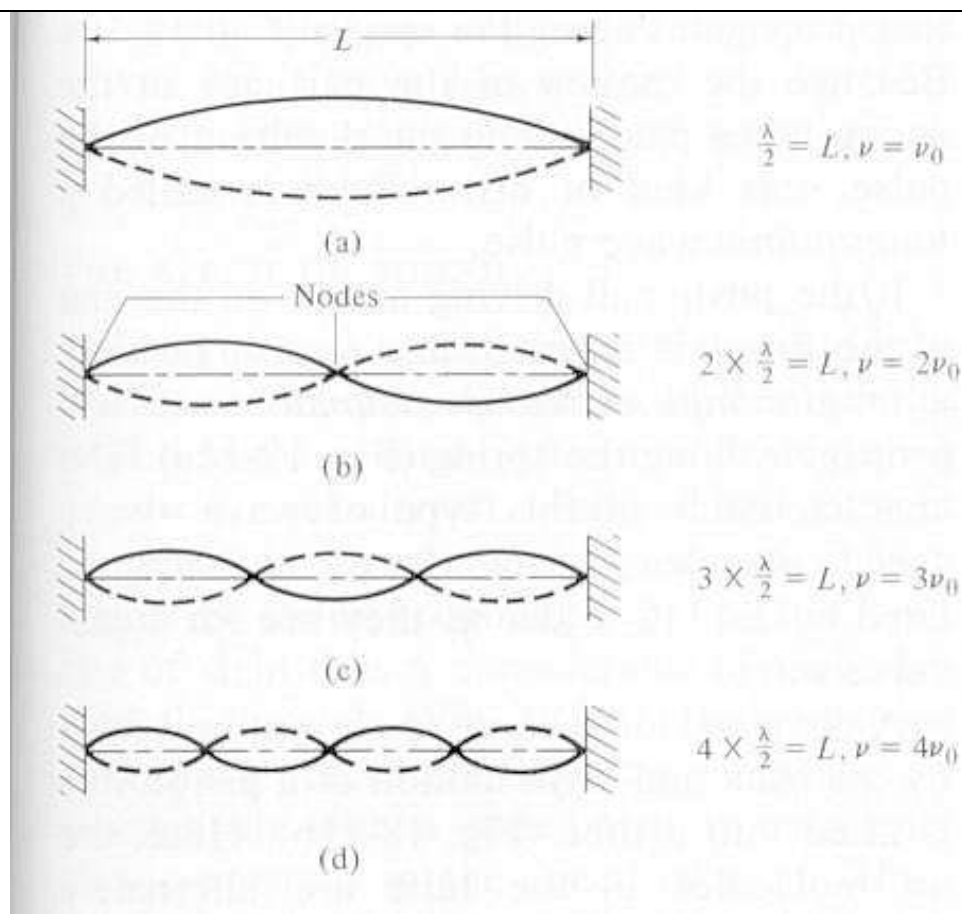
#### Materials:

- Function generator and mechanical vibrator
- String
- Pulley and weights to adjust the tension in the string

#### Suggestions for use:

In this activity students perform 'Melde's experiment' in which one end of a stretched string is attached to a vibrating support and the other end passes over a pulley to a hanging weight, which produces tension in a string. The stretched string is set in motion by the vibrating support, but if the frequency of vibration is not one of the natural frequencies (fundamental or harmonics) of the string the vibrational amplitude of the string is very small. However when the frequency of the vibrating support is the same as one of the natural frequencies the amplitude will be large and will clearly show patterns (nodes and antinodes) of standing waves.

During the experiment the vibration frequency is changed and different patterns of resonant standing waves in a string are observed. The experiment is repeated for a different string tension.



Standing waves in a vibrating string, fundamental frequency and for 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> harmonics. Here,  $\lambda$  is a wavelength of standing wave,  $L$  is the length of the string, and  $\nu$  is frequency of vibrations.

The harmonics are multiples of the fundamental frequency. So, a string of length  $L$  can vibrate with the fundamental frequency:  $f_0 = \nu/2L$  and also with frequencies:  $f_1 = 2 f_0$ ;  $f_2 = 3 f_0$ ;  $f_3 = 4 f_0$ ;  $f_4 = 5 f_0$ ; etc.

This experiment can be done as a demo for a class or in groups. Each group might use a different string tension. The students discover the similar standing wave patterns but for different frequencies. If there is time one might do this experiment with strings of different thickness.

If it is not possible to do this experiment in a classroom the different internet demo's can be used, for example: <http://youtu.be/S7-PDF6Vzc> or <http://youtu.be/MT7EpS4OX3k>.

#### Possible questions:

- Draw different modes of vibrations for other sources (a string has both ends fixed but there are also musical instruments with one fixed end).
- Are these different modes of vibrations also possible in a guitar?

### Activity 2.5. Harmonics of a guitar string

**Learning aims:**

- Understanding how to manipulate a string in order to get the required mode of vibration

**Materials:**

- Guitar or other string instrument to check

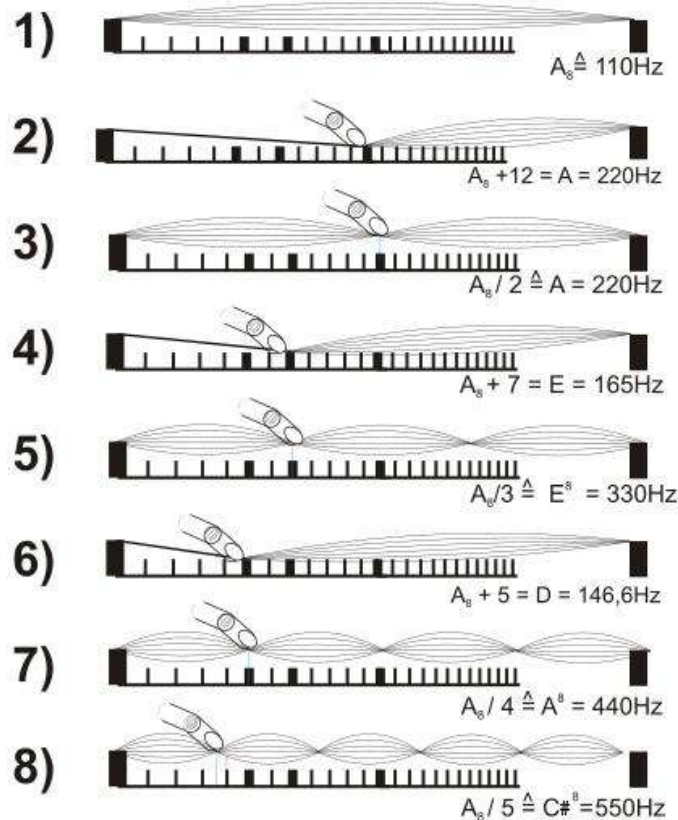
**Suggestions for use:**

In this activity, students apply the knowledge about fundamental frequency and its harmonics to a guitar string.

Harmonics are used to tune the string instrument. The understanding of harmonics is necessary to understand the concept of timbre.

Students watch YouTube video (<http://youtu.be/4NFlic5mi-s?hd=1>) to understand how to produce harmonics on a guitar string.

In similar way they have to produce harmonics on the real guitar.



In the figure above, some harmonics are represented.



**Possible questions:**

- Define other possible positions to touch the string slightly to get the same harmonics as presented here.
- For the situation in the graphic, at which positions could a frequency of 660 Hz be produced?
- Can you hear these different modes of vibrations?
- Which mode of vibration is used in guitar?
- Is this true for any type of musical instruments?

**Activity 2.6. Standing waves in air, closed-end air column****Learning aims:**

- Understanding standing waves in closed-end air column
- Investigate the resonance frequencies of standing waves

**Materials:**

- Sound generator
- Tube,
- Stand material

**Suggestions for use:**

In activity students examine the resonance frequencies of a closed-end column. By changing the frequency of the signal generator the frequency at which air inside of the tube is also changing. When the frequency of signal generator is closed the natural frequency of the air column then resonance occurs and a loud sound results. It is up to the teacher to what extent the students are supported in this experiment.

**Possible questions:**

- How can you, for a certain length of the tube, be sure to have the lowest frequency required for resonance?
- Draw the standing wave patterns for the fundamental frequency and the first three harmonics.
- What would happen with length of the air column or frequency if the speed of sound is changed?
- Predict what the effect will be for the frequency if the temperature is changed.

**Activity 2.7. Standing waves in air: soprano saxophone****Learning aims:**

- Determine relation between the air column  $L$  and frequency  $f$  for conical tube

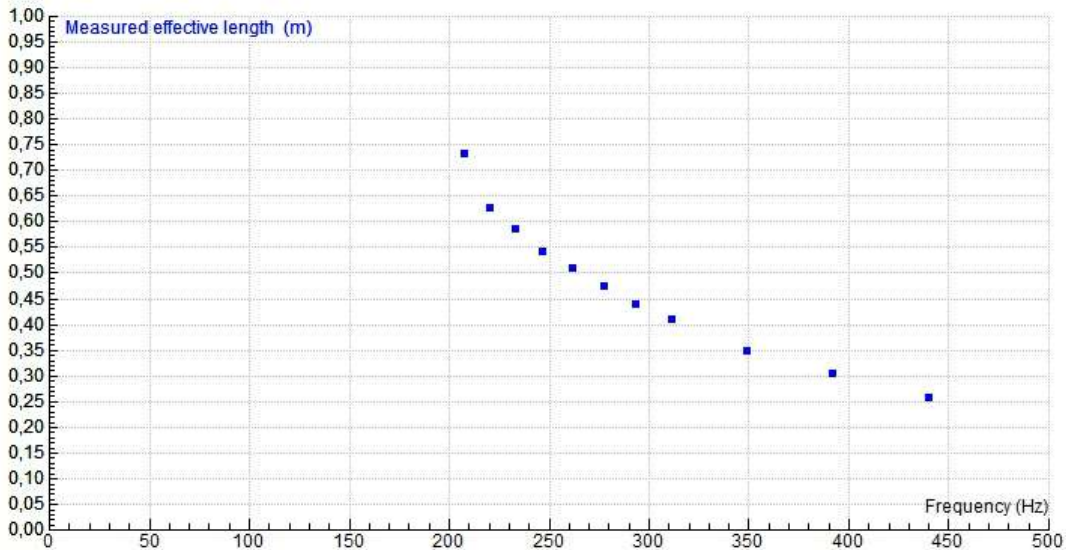
**Materials:**

- Pen and paper (and a worksheet)

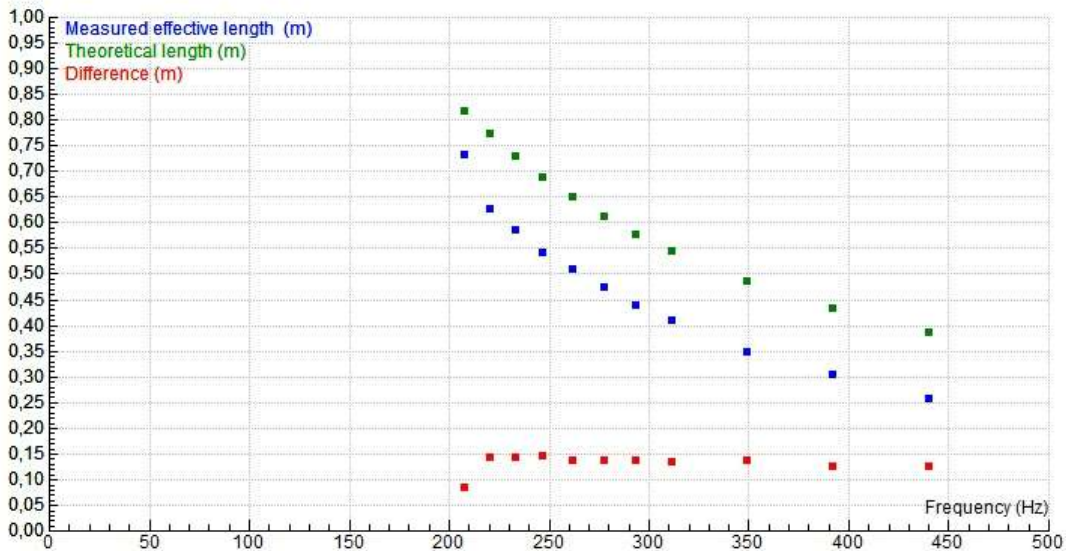
- Coach file with original data

Suggestions for use:

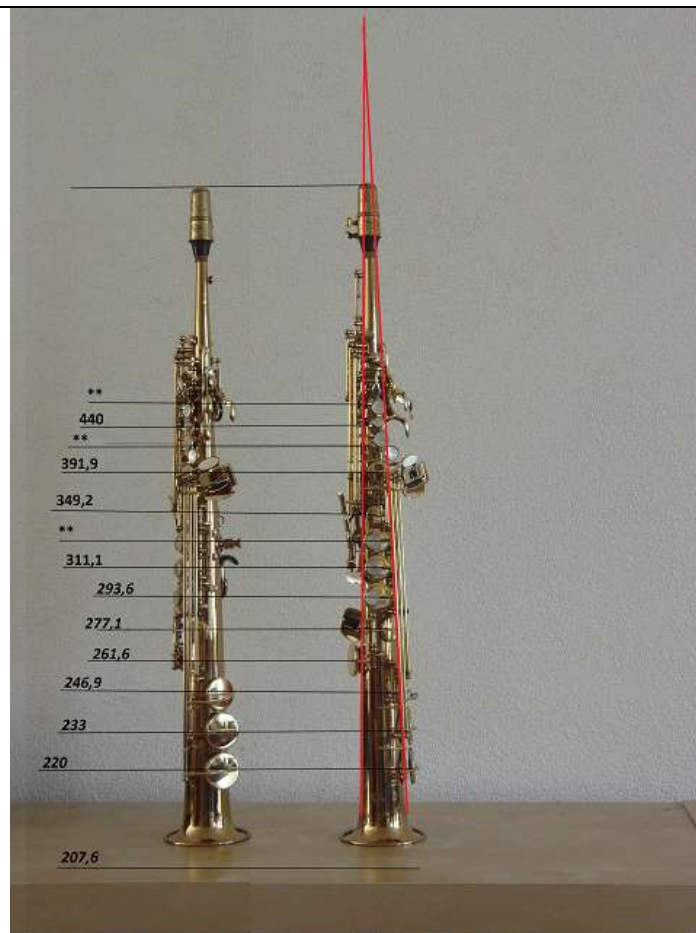
This activity is similar to the one with the guitar and will result in a similar graph. However, the relation between frequency and length is not that simple for a conical tube. Students will find out (and can check this with theory) that the length of the conical tube has to be raised a constant to get a simple relation.



The results based on the original data.



The theoretical value for a cylindrical tube, the measured value and the difference in one diagram. It appears that this difference is indeed a constant.



Determining the constant based on the photograph.

Possible questions:

- Predict what the effect will be for the frequency if the temperature is changed.

### Activity 2.8. Timbre

Learning aims:

- Understanding why different instruments have a different sound

Materials:

- Sound sensor, measuring and analysing software (e.g. Coach 6)

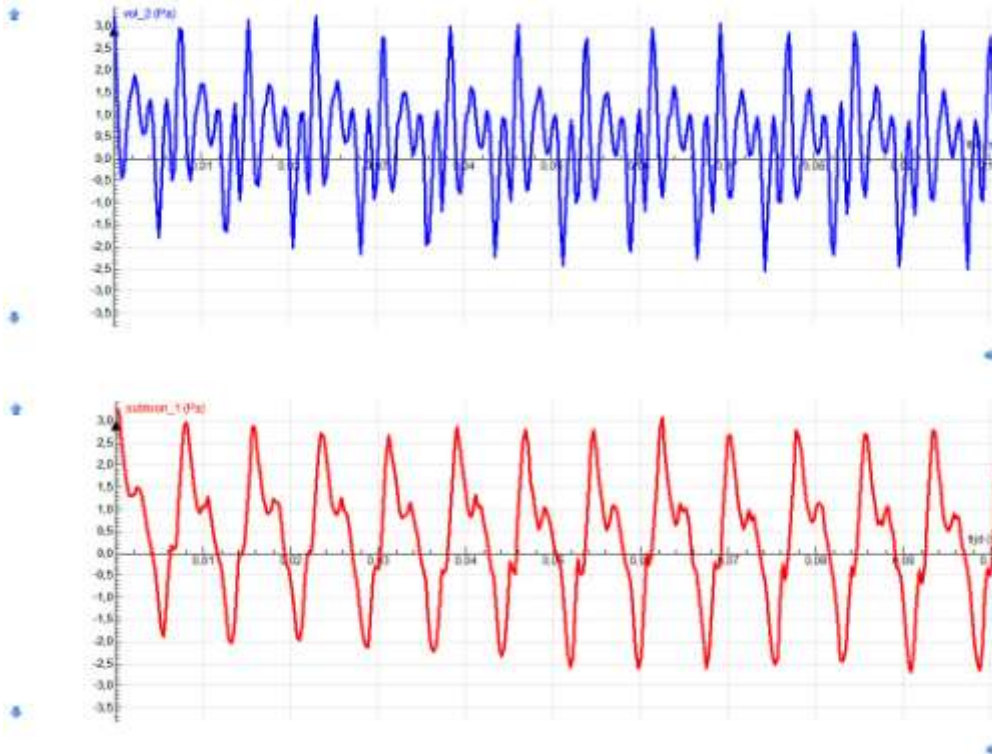
Suggestions for use:

Students should be familiar with sound sensor measurements (for instance Coach 6) and analysing possibilities. When students have the required knowledge on the subject, it is possible to do this as an open inquiry.

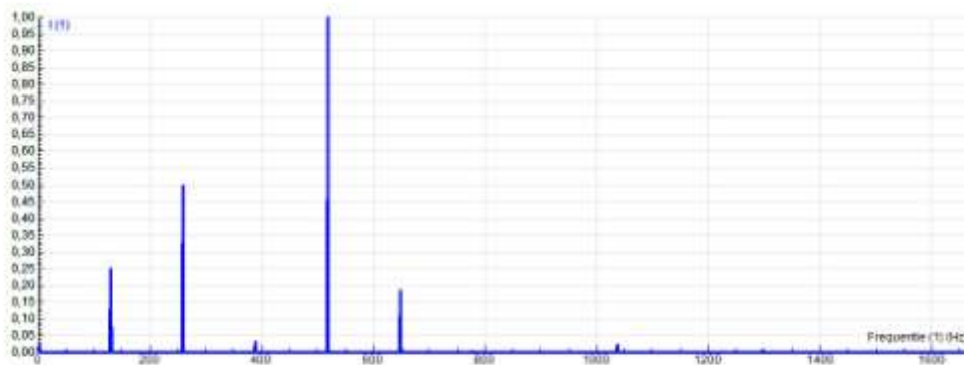
It is possible to divide the class in different groups and let all groups do another instrument. One can think of all the available musical instruments but also bottles or plastic pipes or even the human voice (other possibilities are toys)

See for an example of analysing the timbre of a saxophone: <http://youtu.be/0nff7Lbe9xM>. In this movie, you see and hear the same tone played twice in a different way. In the

diagrams below we see these two tones: the frequency is the same but the shape differs.



Taking a Fourier analysis, shows that the two signals have some components in common but that the first one (with the blue graphs) has a much richer timbre.



**Possible questions:**

- Predict which harmonics are expected, based on the properties of the instrument.
- Check similarities and differences between the sound of instruments and relate this to the type of instrument (why does a trombone and trumpet have sounds that are closely related and why does a violin sounds very different)
- Try to make 'families' of instruments and define the characteristics of sound for each family

**Activity 2.9. Beats****Learning aims:**

- Understanding beats

**Materials:**

- Pen, paper, internet, tuning forks or musical instruments

**Suggestions for use:**

Though the concept of beats is on itself not very hard to understand, it requires some pre-knowledge and in many situations it is no part of the standard curriculum. However, when students have the basic knowledge on sound they should be able to understand the concept of beats. Students can find their own ways and sources to gather information.

**Possible questions:**

- Find examples of beats occurring in daily life.
- Are there musical instruments that use beats?
- Develop an experiment where you demonstrate beats (may be related to music but that is not obliged).

**Activity 2.10. Tuning the guitar****Learning aims:**

- Apply gathered knowledge in a new situation
- Evaluate knowledge

**Materials:**

- Guitar, tuning fork

**Suggestions for use:**

Let the students tune a guitar in different ways. Let them find information on internet about the different tuning methods. Perhaps the students know other ways as well.

The ways to tune the guitar are:

- Using of beats  
One way is to play the same tone on different strings (by shortening one of the strings). Play these tones together, when the two strings are slightly out of tune, beats will occur. When the strings are well tuned, there will be no beat.

See (and hear) for an example of beats on the double bass:

<http://youtu.be/a0VWWbr6O1I> In this movie you see the double bass (starting out of tune) and you can hear the sound of it. This sound is recorded with Coach and you see the beats occurring in the pattern (Around  $t=32$  s in the movie) When the tuning of the strings is changed, you see less beats in the same time ( $t = 56$  s): the strings are more in tune then before. At the end of the movie there are almost no beats ( $t = 1$  m 30 s ). Take notice that the graphs showed in this movie are all given for a measure time of three seconds.

- Using harmonics

By playing harmonics on different strings, the same tone should occur. Let the students find out which frets are used for this.

- Using resonance

When a string that produces a low tone, is shortened, there is a position where this string produces the same tone as the string next to this. Find this position and play the shortened string. When both strings are well tuned, the not-shortened string will resonate.

See for an example of resonance with strings the next movie of a double bass:

<http://youtu.be/d8uH7SeAtZA>.

#### Possible questions:

- Ask fellow students who play the guitar, which method they prefer to tune their guitar
- Which way of tuning the guitar would you prefer?

## Subunit 3 – HUMAN SPEECH

<b>Activity 1.1. Sound graphs</b>
<b>Learning aims:</b>
<ul style="list-style-type: none"> <li>• Introducing of sound graphs (sound amplitude versus time)</li> <li>• Understand that sound graphs can be used for speech recognition</li> </ul>
<b>Materials:</b>
<ul style="list-style-type: none"> <li>• A computer to play MP3 file and files: mama_papa.mp3. Or</li> <li>• A computer with microphone, sound card and Sound analysis program. For example Audacity is a free, open source, sound recorder and editor program. Free to download at <a href="http://audacity.sourceforge.net/download/">http://audacity.sourceforge.net/download/</a>.</li> </ul>
<b>Suggestions for use:</b>
<p>In this activity students are introduced to speech analysis. They analyse simple sound graphs and try to recognise the sound waveforms of certain syllables and words. The students' tasks are given in <i>Worksheet: Sound graphs</i>. Let students perform these tasks. If possible let them work in groups. The given mp3 files can be played on the computer, if possible in the Audacity program.</p> <p>Once students have completed their tasks discuss with them what speech analysis is, how it can be used, what possibilities and difficulties of speech analysis are, etc.</p> <p>This activity should arise students' interest in speech analysis.</p>
<b>Possible questions:</b>
<ul style="list-style-type: none"> <li>• Do you know what speech analysis is?</li> <li>• Do you see any examples or applications of it?</li> <li>• What do you think of the present and future level of technology in this field?</li> <li>• Can you think of societal use and abuse of this technology?</li> <li>• Would you as a judge admit evidence based on speech analysis in court?</li> <li>• Could voice recognition be abused?</li> <li>• Can you come up with commercial applications in the field of advertisement and security?</li> </ul>

<b>Activity 3.2. Model of human speech production</b>
<b>Learning aims:</b>
<ul style="list-style-type: none"> <li>• Understanding the model of the human speech production</li> <li>• Understanding of physics concepts (sound spectrum resonance, formants)</li> </ul>
<b>Materials:</b>
<ul style="list-style-type: none"> <li>• Text about model of human speech production is given in the worksheet</li> <li>• Other internet resources concerning modelling human speech</li> </ul>
<b>Suggestions for use:</b>

In this activity students focus on a model of the human vocal system and physics concepts related to this model.

Hand out *Worksheet: Model of human speech production* and let students read the text. Then discuss with them the given bio-physics model and mechanism of speech production.

Show them the animation of vocal folds at:

<http://www.humnet.ucla.edu/humnet/linguistics/faciliti/demos/vocalfolds/vocalfolds.htm>

Show them X-ray sample movies of human speech:

[http://psyc.queensu.ca/~munhallk/05\\_database.htm](http://psyc.queensu.ca/~munhallk/05_database.htm)

Extend the discussion by asking the questions given below.

#### Possible questions:

- Does temperature influence the pitch of your voice or the pitch of your musical instrument, respectively? In what way? Can you explain the underlying mechanism of this phenomenon?
- Donald Duck is known for his high-pitched speech. Breathing helium will give you temporarily a similar voice. Could you explain this? What property of the intermediating gas is responsible?
- What are the voice differences between man/female, loud/soft, sung/spoken?
- How could we recognize a vowel from its formants?

### Activity 3.3. Sound signal analysis

#### Learning aims:

- Interpreting the recorded speech waveforms
- Determining formants of the recorded speech waveforms by using sound signal analysis tools (e.g. Fast Fourier Transform or Liner Prediction)
- Understanding a spectrogram

#### Materials:

- A sound sensor, interface and software that displays sound waveforms and allows to perform sound analysis (e.g. CMA Coach 6 or Raven Lite program which also produce Sound spectrogram)

#### Suggestions for use:

In this activity students use a sound sensor to record the human voice sounds. Software for recording and analyzing sound is required. It can be for example:

- Coach 6 software together with a sound sensor and interface, or
- Raven Lite program, an application originally developed for use by ornithologists studying bird sounds, can be downloaded at: [http://store.birds.cornell.edu/Raven\\_Lite\\_p/ravenlite.htm](http://store.birds.cornell.edu/Raven_Lite_p/ravenlite.htm) and used for free, or
- Java simulation: Model of the Human Speech Production, which includes as well sound analysis as sound synthesis, available at: [http://www2.spsc.tugraz.at/add\\_material/courses/scl/vocoder/simulation.html](http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/simulation.html)

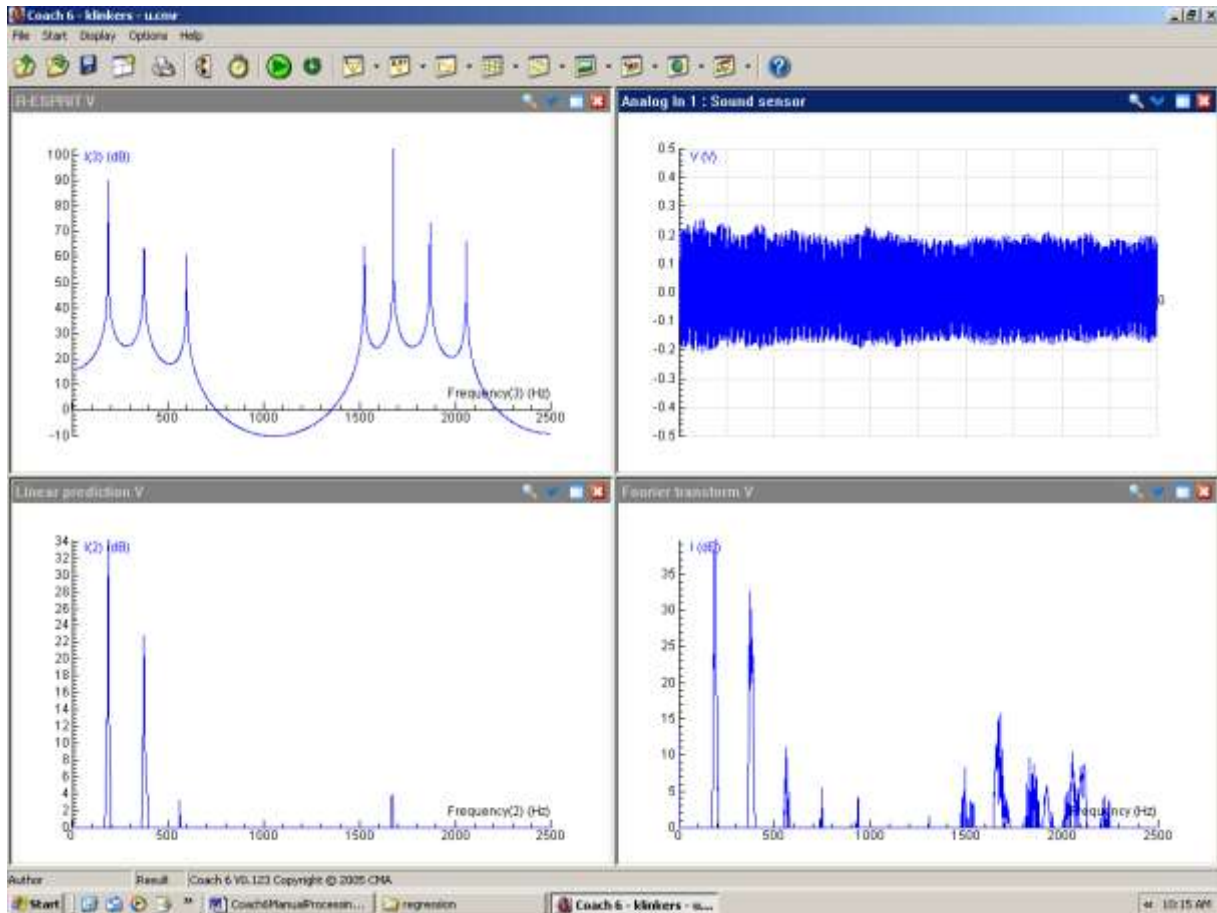
By using Signal analysis tools like Fourier Transform or Linear Prediction students can



display the frequency spectrum of the recorded sounds and find the frequency components.

Analyzing a simple sine wave signal produced by a tuning fork is especially illuminating, since frequencies can be calculated in different ways and compared.

Further students investigate sounds of different vowels and determine the formants of these vowels.



Speech analysis of the vowel 'u' in Coach 6.

In the upper-right diagram the recorded signal is shown (2 seconds of the sound signal has been recorded with a sample interval of 0.2 milliseconds, which gives 1000 data points).

The lower-right graph shows the spectrum resulting from Fourier method, the lower-left graph shows results of the Linear Prediction method and the upper-left corner shows the result of the R-ESPRIT method.

### Possible questions:

- How could we recognize a vowel from its formants?
- Which frequencies determine the voice differences between a male and a female 'aa'-vowel?
- Which frequencies determine the voice differences between a 'aa'-vowel and 'oo'-vowel said in the same pitch.

<b>Activity 3.4. Human speech analysis</b>
<b>Learning aims:</b>
<ul style="list-style-type: none"> <li>Investigating the formants of various vowels</li> <li>Finding and formulating a research question concerning the human speech analysis</li> </ul>
<b>Materials:</b>
<ul style="list-style-type: none"> <li>A sound sensor, interface and software that displays sound waveforms (e.g. CMA Coach 6, Ravel Lite or Java simulation Model of the Human Speech Production <a href="http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/simulation.html">http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/simulation.html</a>)</li> </ul>
<b>Suggestions for use:</b>
<p>In this activity students investigate the human speech analysis. This is an open inquiry in which students learn to find and formulate their own research question without strict guidance of their teacher. They learn to setup and successfully finish (possibly adjust along the way) their own practical experiment. With their conclusions, they practice critical thinking. Finally, they get a good picture of the content and (societal, industrial) applications of speech analysis.</p> <p>The research questions given below give an idea of the scope of possibilities in this subject, they are <i>not</i> meant to share with the students beforehand, as finding their own research question is an important element of this assignment.</p>
<b>Possible research questions:</b>
<p>Below, a number of the research questions are listed:</p> <ul style="list-style-type: none"> <li>What, if any, is the difference in amplitude and frequency between vowels 'a', 'e', 'o', and 'u'? Which property can be used best to distinguish them?</li> <li>How to approach orally the sound of a tuning fork?</li> <li>Analysis and recognition of the sound pattern of the word Earth.</li> <li>How do we recognize gender in the same vowels 'a', 'e' and 'u'? Man versus woman!</li> <li>Is there a difference (if so, which?) between the various ways of pronouncing the vowel 'a': with a pinched nose, behind a cloth, singing, whispering etc.</li> <li>Comparison of the spectrum of a flute and a singing voice, producing the same note.</li> <li>Which (of the lowest five) formant is typical for the sound or the voice, and which for the pitch (height of the tone)?</li> <li>What feature is the most characteristic for a given vowel produced by different people: the relations between the formant frequencies and/or their amplitudes or the absolute differences between them?</li> </ul>

<b>Activity 3.5. Human speech synthesis</b>
<b>Learning aims:</b>
<ul style="list-style-type: none"> <li>Investigating which parameters and how influence the quality of artificial created human speech</li> <li>Finding and formulating a research question concerning the human speech synthesis</li> </ul>
<b>Materials:</b>
<ul style="list-style-type: none"> <li>Software that is able to synthesis recorder sound waveforms (e.g. Java simulation Model of the Human Speech Production)</li> </ul>

[http://www2.spsc.tugraz.at/add\\_material/courses/scl/vocoder/simulation.html](http://www2.spsc.tugraz.at/add_material/courses/scl/vocoder/simulation.html))

### Suggestions for use:

In this activity students investigate the human speech synthesis.

This is an open inquiry in which students learn to find and formulate their own research question without strict guidance of their teacher. They learn to setup and successfully finish (possibly adjust along the way) their own practical experiment. With their conclusions, they practice critical thinking. Finally, they get a good picture of the content and (societal, industrial) applications of speech analysis.

The research questions given below give an idea of the scope of possibilities in this subject, they are *not* meant to share with the students beforehand, as finding their own research question is an important element of this assignment.

### Possible research questions:

Below, a number of the research questions are listed:

- How to make a computer or a robots talk?
- What parameters influence the quality of synthetic speech system?
- What are applications of the human speech synthesis technology?