TEACHING AND LEARNING ACTIVITIES

ACOUSTIC PROPERTIES OF MATERIALS

ORIGINAL VERSION
MATERIALS SCIENCE PROJECT

UNIVERSITY-SCHOOL PARTNERSHIPS FOR THE DESIGN AND IMPLEMENTATION OF RESEARCH-BASED ICT-ENHANCED MODULES ON MATERIAL PROPERTIES

SPECIFIC SUPPORT ACTIONS
FP6: SCIENCE AND SOCIETY: SCIENCE AND EDUCATION

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ACKNOWLEDGMENT
RESEARCH FUNDING FOR THE MATERIALS SCIENCE PROJECT WAS PROVIDED BY THE EUROPEAN COMMUNITY UNDER THE SIXTH FRAMEWORK SCIENCE AND SOCIETY PROGRAMME (CONTRACT SAS6-CT-2006-042942).

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Do you know how long sound has been an interesting area of study for the human being? The architects of ancient Greece were already interested in trying to control the sonority in the theatres that they designed in that period.

From then, many scientists have studied what sound is, how it originated, how it propagates, how to control its qualities, how to record it, how to avoid it, and other questions. The study of sound and sound phenomena led to a scientific discipline called **Acoustics**. Other areas, such as architecture or engineering, take into account the theories elaborated in the field of acoustics when designing structures, precincts and/or technological applications (acoustics of theatres, medical applications such as ultrasound scanning, naval applications such as sonar, audio recording, digital treatment of music, etc).

However, this scientific and technological progress has not been the only motivation to study sound. Social problems also encourage scientists to investigate a certain topic. Nowadays, the problem of sound pollution is already fully recognized. This problem is provoked by all those devices which are useful for human activity, such as machines and motors. The consequences of this problem can be losses of hearing or cardiovascular and nervous system disorders, especially when the sound that provokes the problem has high intensity and the exposure to it is continuous. For this reason, the authorities have passed new laws in order to protect citizens against noise pollution.

This module deals with these problems, focusing on the particular case of a disco which is located near a residential area. It also introduces the necessary scientific and technological elements for being able to understand the problem and provide solutions.
0.1. MAKING SOUNDS WHILE SPEAKING. SPEAKING ABOUT SOUNDS

Throughout the whole sequence you will hear several sounds but you will also have to speak about sound in several situations. This first activity will help you to start getting used to using the vocabulary regarding sound:

a) Produce a sound with your voice or with another object or instrument. One of your partners will have to explain the emitted sound. Next, you will have to take turns.

Write your description:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

b) Now, think about a different sound that you could produce and write what it would be like:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

c) Exchange with a partner the description that you have written and try to produce a sound like the one the other person has described.

Are the sounds produced equal to the descriptions?
Why is it so difficult to exactly reproduce the described sounds?

________________________________________________________________________

________________________________________________________________________

In the former activity you probably noticed how important it is to have a specific vocabulary to be able to understand and communicate efficiently with the rest of your classmates.

WHAT DOES SCIENCE TELL US?

Scientific language is characterized as being more precise than the everyday language we use since the former avoids that the same term or concept can have many different meanings.

For this reason, before starting this sequence, it is important that you remember the scientific language related with the topic of sound, as you will use it along the module.
Next, read the following dialogs:

Conversation between two neighbours
N1: I could not sleep all night long with so much noise in the street!
N2: The loud volume of the music of cars also annoys me very much. However, I suppose that you hear it more because your window looks out onto the main street.
N1: In spite of having double pane windows, hearing so much noise is unavoidable; especially that low and annoying noise caused by some motorbikes without mufflers.

Conversation between the owner of the flat and an expert on acoustics
E: This area where you live has a serious problem with noise pollution! The measurements of the sound intensity level that I have made in your street and inside your flat at various hours are very high.
O: And what do you recommend? We already changed the windows but despite that, the problem persists...
E: We should use certain materials to attenuate the sound that reaches your home, especially sound with low frequencies.

0.2. Find the similarities between the words in *italics* of the conversation between the two neighbours and the words (also in *italics*) used by the expert of the second conversation.

WHAT DOES SCIENCE TELL US?

Before starting to study acoustic properties of materials, you should revise what you already know about sound.

As a starting point, remember what sound is, how it is produced and how it propagates. As you probably know, sound is produced when an object vibrates (e.g., the membrane of a loudspeaker). This vibration pushes surrounding air (or other medium) particles, and these particles oscillate from one side to the other. When oscillating, each particle collides with the one which is near and this one collides with the nearby, and so on and so forth. In this way, the initial vibration is propagated. Therefore, energy is transferred from the initial object which started vibrating to the ears. This transfer does not require transport of matter, since the particles of the medium do not travel but rather oscillate around a point.
WHY DO WE SAY THAT SOUND IS TRANSMITTED BY MEANS OF WAVES?

In Physics, the term wave is used to explain the fact that energy is transferred along a medium without propagation of matter. Therefore, when it is said that sound waves propagate, it means that energy is transferred from one point (e.g., loudspeaker) to another (e.g., ear) by means of the vibration of the particles that are part of the medium. So, sound is not considered any kind of invisible substance which propagates through the medium!

HOW CAN WE DESCRIBE SOUND?

We say that sound is high-pitched when its frequency is high and we say that sound is low-pitched when its frequency is low. Therefore, sound frequency is related to the quality called pitch. We consider that sound is high-pitched if it is produced by an object that vibrates very quickly; whereas a low sound is produced by an object that vibrates slowly. Frequency indicates the number of oscillations or vibrations per unit of time that an object experiments. Therefore, this magnitude describes the speed of vibration of an object and therefore, of the particles of the medium through which the sound wave propagates. The unit of frequency is Hertz (Hz). The human ear can only perceive sounds with frequencies ranging from 20 Hz to 20.000Hz, whereas human voice is able to produce sounds with frequencies between 80Hz and 4000 Hz. Frequency is related to another physical magnitude called wavelength. Wavelength characterizes the size of the wave; therefore, it indicates the distance between two points of the medium where particles are in the same motion state, which means that they are equally separated from their initial position. Our ears can only perceive sound waves which have wavelengths ranging between 3cm and 12m. The more frequency sound has, the faster the particles of the medium vibrate and thus, the less time they spend oscillating and transmitting the vibration to the rest of the particles. Consequently, these sound waves have a smaller size, which means that frequency (f) and wavelength (λ) are inversely proportional magnitudes.

On the other hand, we say that sound is loud or has a high volume when it has a high intensity. We also say that a sound is weak when its level of intensity is low. Therefore, intensity is associated with volume. Sound intensity is the characteristic that gives an idea about the quantity of energy that sound waves transport. In order to make the string of a guitar vibrate, we have to separate it from its equilibrium position and let it free. If we want the guitar sounds louder, we further separate the string of its equilibrium position. Therefore, we transfer more energy to the string. The maximum distance that the string can be separated from its equilibrium position while it is vibrating is called amplitude. Therefore, a louder sound implies a sound wave with greater amplitude.

Sound intensity level is measured in decibels (dB). The scale of decibels is adjusted to the auditory range of the human ear since it goes from 0 dB, which corresponds to the minimum intensity which we can hear, to 120 dB, which is considered the pain threshold for a human being. A calm ordinary conversation can reach near 60dB whereas inside a disco close to the loudspeaker sound can reach 120dB. Sound intensity level can be measured with a special instrument which is called a sound level meter. Sound level meters use a microphone which gathers sound. They have to point at the direction of the sound source.

HOW CAN WE REPRESENT SOUND WAVES?

Sound waves are considered spherical waves because they propagate in all directions from the sound source. In order to represent them, there is one representation which is commonly used: a group of curved lines which have a greater radius as they move away from the source. Each of these lines is called wavefront. The distance between two consecutive wavefronts represents the wavelength. The representation of the “sound ray” is also used to indicate the direction of propagation of sound waves in which most of the energy is transmitted, that is to say, sound intensity level is at a maximum.
UNIT 1: SOUND WAVE – MATERIAL INTERACTION
The owner of a new disco is worried about the noise. The neighbours have already complained about the first sound tests before the inauguration and the owner is aware that, if he does not find a solution, neighbours will report to the police.

The acoustic treatment of the disco has been a problem from the beginning. Initially, there were a lot of mixed sounds and echoes, but the problem disappeared after the installation of furniture and decoration.

In fact, music sounded very nice inside; because it seemed that sound was distributed uniformly around the space. Even behind the loudspeakers! This fact had always surprised him: why does music go everywhere? The problem is that music also reaches the neighbours in spite of the walls in the middle. In order to find a solution, he decided to hire the services of an expert.

DSR enterprise has vast expertise in acoustic conditioning and soundproofing of discos. Their technicians develop projects according to the structural conditions of the building. The design of that disco has lots of possibilities, but the technicians have to take into account the number of people that can go in, the characteristics of each area of the disco (height of ceilings, materials used to make and cover the walls, etc) and decoration.

Next, you can see the specific distribution of that disco. DSR Enterprise divides the disco in different spaces in order to analyze accurately the variables that take part in the acoustic conditions of the disco.
From the images of each sector and the map of the disco, it is possible to identify different elements (e.g., columns, loudspeakers, etc.).

1.1.1. Which characteristics do you think that each of the aforementioned sectors of the disco should have according to the sound intensity level that should be there?

The technicians are working on three basic questions related to the acoustics of the disco:
• In which parts of the disco would it be convenient to hear sound with more intensity? What are the variables that affect the fact that we hear sound louder or weaker?
• What happens when sound reaches an obstacle? Where the loudspeakers should be situated?
• Which conditions avoid hearing sound outside the disco?

Next, you can see a simplified representation of the dance floor of the disco:

1.1.2. DISCUSS WITH YOUR CLASSMATES THE ANSWERS YOU WOULD GIVE TO THE INQUISITIVE QUESTIONS OF THE TECHNICIANS. EXPLAIN YOUR REASONS.

a) What happens to the sound that is emitted by the loudspeaker when it reaches the walls of the disco?
b) Why can I hear the music if I stand behind the loudspeaker?

c) If I am outside the disco, I can not hear the music as loud as when I am inside.

   Why is it not possible to hear it with the same intensity than inside?
One of the engineers of DSR enterprise tells the owner that one of the phenomena to take into account is what occurs when sound reaches a large obstacle (e.g., a wall). It seems that sound “bounces”. The owner needs more information about that “bouncing of sound” in order to take decisions. For instance, he wants to know where he should put the loudspeakers to allow sound to “bounce” in order to be heard in the whole space and he also wants to know what he could do to avoid the “bounce” when it is not appropriate. So, he needs to predict the direction of the sound propagation after it “bounces” and also how to avoid or reduce them.

The acoustic engineer has used an everyday language. However, the scientific term to express the fact that sound “bounces” is different. What do you think this phenomenon is called?

**WHAT DOES SCIENCE TELL US?**

It is not usual to say that sound waves bounce when they arrive at the surface of a material. We say that sound waves are reflected. We call reflection the phenomenon in which waves change their direction of propagation when they reach an object but they continue propagating along the same medium.

**1.2.1. Observe the following picture and try to answer the questions:**
a) Do you think that sound is reflected in the same way on a smooth wall and on a decoration piece which has an uneven surface?  
Why?

b) Where would I hear louder the sound coming from the loudspeaker?  
Why?

In which direction is sound reflected?  
Analyze how some objects bounce (e.g., pool balls), or how other waves are reflected (e.g., laser beam) over smooth surfaces. Notice the directions of propagation of the balls and the laser beam.

The angle formed by the direction of propagation of the incidental sound ray with the perpendicular line to the interface between two mediums (broken line in the picture) is called angle of incidence. The angle of reflection is that formed by the direction of propagation of the reflected sound ray with the normal line.
1.2.2. Which kind of relationship do you think exists between both angles?

1.2.3. Measurement of the angle of reflection in which sound intensity level is highest

We could measure this angle with an experimental setup like that shown in the picture:
• On the left, there is a sound source, which is called a buzzer and is emitting inside a pipe made of PVC.
• The pipe is aimed at a smooth surface (e.g., wood veneer) in a way that the angle of incidence is 45°.
• Placing a sound level meter in different directions, the sound intensity level is measured.

What happens when the experiment is performed?
After turning the buzzer on and measuring sound intensity level as the direction of the sound level meter was varied, the following results have been obtained:

<table>
<thead>
<tr>
<th>ANGLE OF REFLECTION</th>
<th>DIRECT SOUND</th>
<th>0°</th>
<th>30°</th>
<th>45°</th>
<th>60°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOUND INTENSITY LEVEL (dB)</td>
<td>74.8</td>
<td>67</td>
<td>67</td>
<td>67.4</td>
<td>66.8</td>
<td>65.8</td>
</tr>
</tbody>
</table>

Explain the results of this experiment.

Why can you hear sound coming from a source at any point of a room, independently from where you are situated?

The fact that the angle of incidence and the angle of reflection are equal can be tested experimentally.
1.2.4. In conclusion:

a) Complete the sentence: When sound propagates in a certain direction and reaches an obstacle (its surface), it is reflected, that is...

b) Complete the sentence: The direction of propagation of the reflected sound ray is...

c) Draw the reflected sound ray using an arrow and represent the propagation of the reflected waves using wavefronts. Mark the angles of incidence and reflection.

Some surround sound systems take advantage of the property of sound reflection in certain directions to amplify the sound the listener hears. Part of the sound will directly reach the listener and another part will reach him after being reflected on the walls.
REFLECTION AND AUDITORIUM CEILINGS
In some rooms, ceilings are modified to avoid too much reflection towards the audience. For this purpose, materials or objects with uneven surfaces are used. These materials reflect sound in different directions, that is, sound is diffused. These kinds of materials are called sound diffusers.

1.2.5. The following pictures show three rooms allocated to different uses.

Which of them do you think have used sound diffusers?

WHICH PATH DOES THE SOUND FOLLOW FROM THE LECTURER TO THE LISTENER IN AN AUDITORIUM?
In very big rooms with high and smooth ceilings, notice the path that sound follows from the lecturer (sound source) to the listener.

Part of the sound is reflected on the ceiling or the walls. Another part is not reflected (direct sound).

1.2.6. a) Looking at the picture above, which part of sound would you say (direct or reflected) will reach the listener later?

Why?
b) If different parts of sound follow different paths and, therefore, some of these parts are delayed in reaching the listener, do you think that the listener would hear sound as if it had more duration or would hear different sounds?

Explain your answer.

WHAT DOES SCIENCE TELL US?

In wide closed spaces, such as theatres or lecture rooms, it is usual to hear that sounds last more than they do normally. This phenomenon is called reverberation and is due to sound reflection. Reflected waves are delayed in respect of direct sound for a time small enough so that the human ear is not able to distinguish the two different sounds. The human ear can only appreciate a sound with greater duration. If this delay is substantial, the phenomenon is called echo.

The reverberation in a closed space is characterized by the **reverberation time**. This is the time from when the sound is produced until its intensity diminishes enough not to be heard. It is an acoustic characteristic of each closed space.

REVERBERATION TIME

The time that sound remains being heard after having been emitted (also called reverberation time) has been measured in a room which has high and smooth ceilings. The graph on the left represents the time that sound continues being heard in the big room. Once the room has been acoustically conditioned using objects with irregular surfaces and materials that reflect very little sound, the measurement of the reverberation time has given place to the graph on the right.
1.2.7. a) Which differences do you observe between both graphs?

b) When would the words of the lecturer be more intelligible, before or after acoustically conditioning the room?

Why?

Each closed space has an ideal reverberation time depending on the function that it has. A room allocated to make lectures or plays needs a short time of reverberation so that sound that reaches the audience is very clean and comprehensible. However, in a room allocated to listen to music, the largest reverberation time is needed to improve the acoustic sensation, avoiding musical sounds from finishing in an abrupt way and attenuating them slowly.

<table>
<thead>
<tr>
<th>USE OF THE ROOM</th>
<th>IDEAL REVERBERATION TIME (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theatre and lectures</td>
<td>0,4 – 1</td>
</tr>
<tr>
<td>Chamber music</td>
<td>1 – 1,4</td>
</tr>
<tr>
<td>Orchestral music</td>
<td>1,5</td>
</tr>
<tr>
<td>Opera</td>
<td>1,6 – 1,8</td>
</tr>
<tr>
<td>Choral and sacred music</td>
<td>Up to a 2,3</td>
</tr>
</tbody>
</table>

1.2.8. Some people think that the Palau de la Música Catalana is a room which is “excessively muffled” for orchestral music. An expert on acoustical architecture measured the average reverberation time of this room and obtained an approximate value of 1,2s.

Do you think that this measurement corroborates the listeners’ opinion? Explain your answer.
The owner of the disco is more relaxed now that some of the problems are beginning to be solved. He is looking forward to starting it up and even has already decided the music that he will personally deejay in the disco. Even so, he does not want to neglect his duty with the neighbours, who are very anxious since they have been informed about the kind of business he will set up. He thinks that his music is quite pleasant, but there is no accounting for tastes.

Below you can see a simplified representation of the disco and one of the adjacent houses which is separated from the disco only by a wall:

![Diagram of disco and adjacent house]

1.3.1. a) How would you explain the fact that neighbours can hear the music coming from the disco?

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b) Do you think that the neighbours would hear less music if the sound reflection inside the disco was increased?  

*Why?*

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In order to propose a solution for attenuating sound outside the disco, first the engineer must measure the intensity level of sound produced inside the disco and sound that arrives at different points outside the disco, in the street and in the flats situated on the top and the sides of the disco. The engineer uses a sound level meter that measures the sound intensity level that reaches it in dB. The more decibels it indicates, the more intense the measured sound is.
1.3.2. HOW CAN WE MEASURE THE VARIATIONS OF THE SOUND INTENSITY LEVEL?
Now you will learn to use this device for measuring the sound intensity level. Moreover, you can take advantage of using the sound level meter connected to an interface which allows you to save the measured data in the computer and to analyze them from graphs and tables, as the picture shows. This equipment will allow you to observe the graph of the variations of the sound intensity level throughout time, on the computer screen.

IN ORDER TO TAKE MEASUREMENTS USING THIS EQUIPMENT, IT NEEDS TO BE CONFIGURED. FOLLOW THE CONFIGURATION GUIDELINES.

---

**a)** Produce sounds with different intensities (whistling, speaking loudly and quietly, keeping silent, with a device*, etc) in front of the microphone of the sound level meter. Observe on the computer screen how different sounds are represented graphically.

*BUZZER CONNECTED TO A BATTERY OR CELL*
b) Draw in the following axis the graph obtained for the sounds you have emitted. Identify in the graph which kind of sound you were producing in each time interval. Mark in the graph the moments in which the sound intensity level was high.
1.3.3. How does the sound level meter – buzzer distance affect the measurements of the sound intensity level?

a) Before analyzing the influence of the distance on the measurements, you should think about how it can affect and draw your prediction in the following axis. Represent the graph that you think you will observe on the computer screen when you move the sound level meter away from the sound source.
b) Now proceed to measure this variation of the sound intensity level. Move the sound level meter steadily away from the buzzer. Draw the obtained graph in the following axis:

![Graph with axes labeled TIME (s) and SOUND INTENSITY LEVEL (dB)]

c) Discuss briefly the similarities and differences between your prediction and the obtained graph.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

d) From the obtained graph, explain how the sound level meter – buzzer distance affects the measured values of the sound intensity level.

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________________________________________________________________________
WHAT DOES SCIENCE TELL US?

When sound propagates through a medium, its intensity diminishes with distance, since sound waves propagate in all directions and therefore, its energy per unit of area is reduced by the spreading of the wave.

COMPARING SOUND INTENSITIES. HOW MUCH SOUND IS TRANSMITTED THROUGH THE WALLS?

The technician places a loudspeaker inside the disco and adjusts it to emit sound with 500 Hz and 100dB. In the following table, you can observe the measurements taken in the neighbour’s house at night, which correspond to the values of the sound intensity there if the disco is only separated from the houses by everyday building elements (concrete walls, bricks):

<table>
<thead>
<tr>
<th>FREQUENCY (Hz)</th>
<th>EMITTED SOUND (dB)</th>
<th>TRANSMITTED SOUND (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>100</td>
<td>58</td>
</tr>
</tbody>
</table>

1.3.4. a) Compare the emitted and transmitted sound intensity level. What is your conclusion?

__________________________________________________________________________

b) Which sound intensity level has not reached the other side of the wall?

__________________________________________________________________________

1.3.5. What has happened to the part of sound that has not been transmitted?

__________________________________________________________________________
WHAT DOES SCIENCE TELL US?

The sound decrease produced when part of the sound is not transmitted through a material is called **attenuation**.

When sound reaches the walls of the disco, the air particles that collide with the particles that are part of the walls bounce and collide again with the adjacent air particles. Therefore, we say that part of the sound is reflected. Moreover, the particles that are part of the material of the wall will also start to vibrate due to the collisions with the air particles, transmitting sound to the other side of the wall. We say that part of the sound has been transmitted. However, due to the vibration of the particles that are part of the material of the wall, these will increase their motion and therefore, the temperature of the material will increase (even the increase would not be noticeable).

In other words, when sound reaches an object, part of its energy is reflected (reflected sound) and another part penetrates into the wall. From this latter part, part of the energy is transferred to the object (absorbed energy) and another part is transmitted again through the object and it reaches the neighbours’ house (transmitted sound). As sound has an associated energy, we can say that the energy of the incident wave which hasn’t been transmitted to the other side of the object corresponds to the energy that has been attenuated.

\[ E_{\text{attenuated sound}} = E_{\text{incident sound}} - E_{\text{transmitted sound}} = E_{\text{absorbed}} + E_{\text{reflected sound}} \]

Therefore, sound attenuation is due to both **reflection** and **absorption**.

As sound intensity is related to the energy that it has associated, we can calculate attenuation as the subtraction between the emitted and the transmitted sound intensity level.

\[ I_{\text{attenuated sound}} = I_{\text{incident sound}} - I_{\text{transmitted sound}} \]
When the engineer finishes his measurements, he tells the owner of the disco that his business doesn’t fulfil the regulations because a transmitted sound lower than 30 dB is required.

To solve the problem, the engineer warns the owner that the sound has to be reduced. His proposal is to use sound reflecting materials or sound absorbing materials. In fact, he suggests a solution combining both kinds of materials.

**WHAT DOES SCIENCE TELL US?**

The material called **sound reflector** is the one which reflect most of the sound that reaches its surface.

The material called **sound absorber** is the one which absorb most of the sound which has penetrated it.

All materials reflect, absorb and transmit (a lot or a little) the sound which reaches them. However, we say that a material **is a sound insulator** when it attenuates sound a lot, which means when it transmits a small amount of sound energy and, therefore, reduces the intensity level of sound a lot. As sound attenuation is due to reflection and absorption, any good sound reflector or sound absorber or any combination of both materials is considered a sound insulator.

1.3.6. The following diagrams represent the process of energy transfer when airborne sound waves reach an object.

![Diagram of energy transfer](image)

a) Which diagram represents a sound reflector and which one represents a sound absorber?
b) Explain your answer.

---

**1.3.7. How can we test empirically if a material attenuates sound a lot or a little?**

The owner of the disco does not know yet which materials he should use to line the walls of the disco in order to attenuate the sound which reaches the neighbours. In order to answer this doubt, it would be advisable to design an experiment in order to test if certain materials or objects are good at attenuating sound. If you were the owner of the disco:

a) How would you test if the materials you have chosen to line the walls and the ceiling with are appropriate to attenuate the sound emitted by the loudspeakers of the disco?

---

b) How would you know which attenuation has been achieved in the neighbours’ house when using a certain material?

---

c) Next, draw a diagram of the experiment you would carry out in the classroom or in the laboratory to test if a material attenuates sound a lot, that is, if it reduces the intensity level of transmitted sound a lot:
1.3.8. Let’s perform the designed experiment to test if a material attenuates sound a lot or a little

Before performing the designed experiment, you should take into account the distance you have planned to put the sound level meter away from the sound source. Remember that the measurements of the sound intensity level depend on the distance between the sound level meter and the sound source.

Proposal: To measure the intensity level of the incident and the transmitted sound in the same conditions of distance, measure the distance between the sound source and the end of the sound level meter. Write down the distance and take the measurements taking it into account.

\[ d = \text{__________ m} \]

Remember that you will also need to know the intensity level of the emitted sound which reaches the sound level meter. This value will be the reference value which will allow you to know if the sound transmitted through a material or object has been attenuated a lot or a little.

a) Perform the designed experiment. Fill in the table with the obtained values:

<table>
<thead>
<tr>
<th>INTENSITY LEVEL OF THE INCIDENT SOUND (dB)</th>
<th>INTENSITY LEVEL OF THE TRANSMITTED SOUND (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) Finally, calculate the attenuated sound:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
1.3.9. Let’s organize our ideas!

As a summary of the first part of this sequence, try to organize your ideas explaining what you have learnt up to now.

Elaborate a text to answer the following question:
“How can we manage to avoid hearing too much sound outside the disco?”

Use the concepts that you have studied along these units: Sound propagation, reflection, energy, intensity, absorption, transmission, attenuation, materials, sound absorbers, sound reflectors, sound insulators

You can add other concepts that you consider necessary to answer the question.

EXCHANGE YOUR TEXT WITH THE ONE WRITTEN BY ONE OF YOUR CLASSMATES. ASSESS THE TEXT MUTUALLY (USING A DIFFERENT COLOUR) AND TRY TO IMPROVE YOUR TEXT IN COLLABORATION WITH YOUR CLASSMATES.
UNIT 2: PROPERTIES AND INTERNAL STRUCTURE OF SOUND REFLECTORS AND SOUND ABSORBERS
The sound that reaches the houses from the disco may annoy the neighbours. Some of them are thinking of ways to reduce the noise; meanwhile others are considering that it is the owner who has to make the decisions. That’s why the owner asked for a solution from the engineer from a company since he was already aware of the problem and considered that he had to find ways to attenuate the sound that is emitted from his bar. A constructive solution that seemed to solve the problem was proposed by the engineer. However, the technical recommendations were not completely followed and the solution failed. The money that the owner of the disco wanted to save will now have to be spent on covering all the walls and ceilings of the disco, using laminated plates made with different materials. These materials should have certain characteristics so that they can attenuate the sound that reaches the neighbours. Nevertheless, this is in order to reduce the sound intensity level to acceptable values.

2.1.1. As you could see in the previous section, sound reflectors and absorbers behave differently in front of sound: some of them reflect sound on its surface. Meanwhile, the others attenuate the sound that is propagating inside them and absorb part of the sound energy.

a) Which properties do you consider sound reflectors to have in common?

b) And sound absorbers?
2.1.2. Students from another secondary school have also thought of some characteristics that sound reflectors and absorbers have. What do you think about what they think?

a) Write in the following table, if you agree (A) or disagree (D) with each of the students’ sentences, explaining your answer.

<table>
<thead>
<tr>
<th>STUDENTS’ ANSWERS</th>
<th>A / D</th>
<th>JUSTIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. “Porous materials or made of fibres are good sound absorbers”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. “Very dense materials are good sound reflectors”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. “Sound absorbers have very separated particles”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. “The thicker a material is, the better sound reflector it is”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. “Sound absorbers are usually flexible”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. “Sound reflectors have smooth surfaces”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. “Soft materials are good sound absorbers”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. “Sound reflectors are made of a lot of particles”</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) Discuss with your partners which characteristics a material must have to be considered a sound reflector or absorber respectively, explaining your reasons.

c) Fill the squares below with the characteristics that you have agreed during the idea-sharing.
2.1.3. Which materials will behave as good sound absorbers or reflectors?

Now that you have already discussed which characteristics of sound absorbers and sound reflectors are relevant to their acoustic behaviour, below you are given some samples of materials for you to observe and predict if these materials will behave as good sound absorbers or reflectors.

Explain your answer.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>A / R</th>
<th>JUSTIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium foil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Felt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyurethane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chipboard with Formica</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass wool</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.1.4. How can we test empirically if a material is a sound absorber or reflector?

The owner of the disco needs to know how to identify whether a material is a sound absorber or sound reflector in order to use one or the other in each space of the disco. In some areas sound should be amplified in order to hear loud music; in other spaces it is necessary to hear clear sounds so that people can talk without having to shout. In all the areas it is necessary to take into account that sound that reaches the neighbours must be constricted. For this reason, he would need to design an experiment in order to test if certain materials are good sound reflectors or absorbers.

a) How would you test whether the materials that you will use to cover the walls and the ceiling of the disco are sound reflectors or absorbers?

b) Next, draw a diagram of the experiment you would carry out in the classroom or in the laboratory in order to test if a material is:
   - A sound reflector, that is, it reflects a great deal of sound which reaches it, or,
   - A sound absorber, that is, it absorbs a great deal of sound energy that reaches it.
c) Share your proposals with your classmates in order to decide the experiment that you will carry out to measure whether a material is a sound reflector or absorber.

d) Once you have reached an agreement on the experiment that you will perform, modify with a different colour the drawing of the experimental design that you have made.
2.1.5. Testing whether certain materials are sound absorbers or reflectors

In the previous activity you have discussed how to test analytically if a certain material is a sound absorber or reflector. Suggested below is a specific experimental design using boxes covered inside with different materials (look at the figure). These boxes have a little hole in one side so that you can introduce the microphone of the sound level meter inside the box when you want to measure the sound intensity level inside.

As a sound source, you can use a buzzer or a mobile phone. The sound source can be put inside one of the boxes and the microphone of the sound level meter would be introduced inside the hole in the box.

Measure the sound intensity level inside each box in order to distinguish between sound reflectors and sound absorbers.

First, you would need to know the reference sound intensity which you will have to compare with the rest of measurements in order to determine if sound inside the box has been attenuated or has been amplified. This reference value corresponds to the measurement of the sound intensity level inside the cardboard box (without being covered by any material). Next measure the sound that reaches the sound level meter when it is inside each box covered with a certain material. Having done this comparison, you will determine if the box is covered with a sound absorber or sound reflector.
a) If the sound intensity level measured inside a box covered with a certain material increased above the reference value, which kind of material would be covering the box? And if the level decreased below the reference value?

b) Remember that the distance affects the measurements of the sound intensity level. Therefore, keep it fixed.

SOUND SOURCE INSIDE THE BOX

Write down the value of the sound level meter – buzzer distance at which you will measure:

\[ d = \underline{\text{\phantom{0}}} \text{ cm} \]

Fill in the following tables with your measurements:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>SOUND INTENSITY LEVEL INSIDE THE BOX (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium foil</td>
<td></td>
</tr>
<tr>
<td>Felt</td>
<td></td>
</tr>
<tr>
<td>Polyurethane</td>
<td></td>
</tr>
<tr>
<td>Chipboard with Formica</td>
<td></td>
</tr>
<tr>
<td>Glass wool</td>
<td></td>
</tr>
</tbody>
</table>
c) From the obtained values, answer which of these materials are sound reflectors and which ones are sound absorbers.

<table>
<thead>
<tr>
<th>SOUND REFLECTORS</th>
<th>SOUND ABSORBERS</th>
</tr>
</thead>
</table>

2.1.6. Which properties do sound reflectors and sound absorbers have?

In the previous experimental activity you have classified empirically some materials depending on whether they are sound reflectors or absorbers. Now you will observe these materials in order to determine which properties they have so that they behave acoustically in the way they do.

a) Fill in the following table describing which properties (density, rigidity/flexibility, porosity, shape of the surface, thickness, etc.) you consider each of these materials to have:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium foil</td>
<td></td>
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<tr>
<td>Felt</td>
<td></td>
</tr>
<tr>
<td>Polyurethane</td>
<td></td>
</tr>
<tr>
<td>Chipboard with Formica</td>
<td></td>
</tr>
<tr>
<td>Glass wool</td>
<td></td>
</tr>
</tbody>
</table>

b) Of the sound reflectors you have tested, what properties do they all have in common? What properties do the sound absorbers all have in common? Share your answer with your partners.

<table>
<thead>
<tr>
<th>SOUND REFLECTORS</th>
<th>SOUND ABSORBERS</th>
</tr>
</thead>
</table>
c) Of all the properties that you have just assigned to sound reflectors and absorbers, distinguish the properties which are specific or characteristic of materials (such as aluminium) and those which are general and correspond to objects made of certain materials (such as the aluminium foil or a plate of wood).

<table>
<thead>
<tr>
<th>PROPERTIES OF MATERIALS</th>
<th>PROPERTIES OF OBJECTS</th>
</tr>
</thead>
</table>


d) Compare only the properties that you have considered common to all the test materials (not properties of objects) and those properties of materials assigned to sound reflectors and absorbers in activity 2.1.2.

Are there any properties that you are not sure if they characterize sound reflectors or sound absorbers? Why?
WHAT DOES SCIENCE TELL US?

Here you can read the definition of the physical properties of materials that you have mentioned in the previous activities:

DENSITY

Remember that density is the physical property which indicates the relationship between mass and volume of a certain material. Therefore, if we compare the density of two samples of different materials with the same dimensions, we can say that one material is denser than the other if it weighs more, that is, if it has more mass (having the same volume).

RIGIDITY / FLEXIBILITY

We say that a material is rigid when it is very difficult to deform it, that is, when it is necessary to apply great force in order to deform it a little. Flexible materials can be deformed very easily when a little force is applied to them. So, the rigidity is the resistance that a material puts up to be deformed under the action of an applied force.

POROSITY

Porosity is defined as the quantity of empty spaces (full of air) in the total volume of a material. We can test that a material is porous by putting it into water. If it does not absorb water, it will mean that its cells are closed. Therefore, we do not consider it porous. If it is porous, it will slowly absorb water because its pores are interconnected.

2.1.7. Working with more precise data on properties

Knowing the properties of a material is very important in order to predict its acoustic behaviour (if it is a sound reflector or absorber), before testing it experimentally. Now you will work with some data about the materials that you have tested in the laboratory in order to test if sound reflectors and sound absorbers have the properties that you imagined at the beginning.

Describe the properties of each of the samples of material that you have tested, filling each column of the following table from: (a) the manipulation and direct observation of the materials (rigid, flexible, smooth, uneven, with fibres, porous, with cavities, formed by little balls, ...); (b) the observation of the photographs of the internal structure of these materials obtained with a binocular magnifying glass (approximately 40x) and available in the technical sheets and; (c) the experimental results obtained in the previous activities.
<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>DENSITY (g/cm³)</th>
<th>RIGID / FLEXIBLE</th>
<th>OBSERVATION OF THE STRUCTURE AT THE NAKED EYE</th>
<th>OBSERVATION OF THE STRUCTURE WITH MAGNIFYING GLASS (40X)</th>
<th>REFLECTOR / ABSORBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>2,70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Felt</td>
<td>0,33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyurethane</td>
<td>0,13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chipboard with Formica</td>
<td>0,70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass wool</td>
<td>0,02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.1.8. Final conclusions

Use the data from the previous table to draw conclusions on the properties of sound reflectors and sound absorbers. Fill in the following table with your conclusions about which physical properties sound reflectors and sound absorbers have:

<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>SOUND REFLECTORS</th>
<th>SOUND ABSORBERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rigidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porosity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.1.9. To know more

One hot summer night, the girl who lives on the first floor of the building tried to sleep, having the window open. She had to get up early but the noise coming from the disco kept her from falling asleep. Meanwhile, her father was sleeping peacefully and did not hear the noise because he had lost his hearing at work.

Although the night was very hot, she closed the window, which was made of aluminium with a double-layer of glass, and spread out the thick curtains of cotton and polyester. The noise became softer but was still unbearable; it seemed as if the noise was going through the walls of the building, made of bricks and cement. The noise even went through the fitted carpet, made of hemp fibre.

She was desperate, so she covered her head with a cushion. The noise had a lower intensity but she could hardly breathe. Suddenly, she remembered that her mother had some earplugs for emergency situations. She found them. They seemed to be made of foam. Following the instructions on the package, she compressed the earplugs forming a little ball and put them inside each ear. Although both earplugs fitted well, she still heard a faint noise that seemed to arrive from far away. Finally, the girl fell asleep. She was looking forward to the soundproofing of the disco!

Different objects and materials have been mentioned in the text: concrete, fabric made of cotton, bricks made of clay, earplugs, fabric made of polyester, hemp fibre, etc.

*Describe the physical properties of these materials and predict their acoustic behaviour.*

<table>
<thead>
<tr>
<th>Foam (Earplugs)</th>
<th>DESCRIBE THEIR DENSITY, RIGIDITY AND POROSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Foam" /></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Synthetic foam</th>
<th>DESCRIBE THEIR DENSITY, RIGIDITY AND POROSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2" alt="Synthetic foam" /></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>Describe their density, rigidity and porosity</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Cotton (fabric)</td>
<td></td>
</tr>
<tr>
<td>Hemp (fibre)</td>
<td></td>
</tr>
<tr>
<td>Polyester (fibre)</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
</tr>
<tr>
<td>Clay (bricks)</td>
<td></td>
</tr>
<tr>
<td>Choose another common material</td>
<td></td>
</tr>
</tbody>
</table>
Which of them do you think would behave as sound reflectors?

Which of them do you think would behave as sound absorbers?
In the previous activities, we have related the sound attenuation capacity of different materials with certain properties: rigidity, density and porosity. The fact that these materials present these properties has to do with their internal structure. You have empirically tested that the more dense and rigid and less porous materials reflect sound a lot and, on the other hand, less dense and rigid and more porous materials absorb sound a lot. The following activity will help you to establish a model to interpret how a material behaves in front of sound in terms of its internal structure.

**Attenuation by reflection: what are sound reflectors like inside?**

**2.2.1. Very or little dense materials**

When a material is very dense (it has more mass per unit of volume) is more resistant to be moved.

a) Next, there is a drawing where you can observe a scale with two samples of different materials, which are represented with the particulate model of matter. If both have the same volume, which material is denser?

*Why?*

As you already know, sound waves are propagated when the particles of a medium vibrate and transfer the energy from some particles to the others in every collision between them.

In order to understand how density affects the fact that a material reflects sound a lot or a little, you might think about pool. Imagine that the white ball represents one air particle, which collides with the particles of a material object to transmit sound. The colour balls would represent the particles of this material with which air particles collide.

Imagine now that the white ball collides with two different sets of coloured balls. The same set of balls is formed by the same kind of balls but the two sets are different one from the other because of the mass of the balls that are part of them. Both sets of coloured balls represent two different materials formed by particles with a different mass: the particles of material 1 have more mass that those that are part of material 2. Imagine that both materials have the same volume and are formed by the same number of particles bounded between them.
a) Which material is denser?

b) Which kind of ball will be more difficult to be moved?

c) If the white ball collides with both sets of balls with the same force, which of them will make the white ball bounce with more velocity, that is, which ball will return more energy back to the white ball?

2.2.2. a) What does it mean in terms of internal structure the fact that a material is denser?

b) Think of an explanation about how the density of a material affects its acoustic behaviour, that is, the fact that the material reflects sound a lot or a little, using the particulate model of matter.
2.2.3. Very rigid or less rigid materials

Rigid materials are very difficult to deform.

In order to understand how rigidity affects the fact that a material reflects sound a lot or a little, you could use the following ball and spring model. This model represents a solid object as a lattice of particles (balls) linked by means of some kind of bond (springs). Depending on these bonds, the connection between particles will be more or less strong and, therefore, will be more or less difficult to deform the object.

BALL AND SPRING MODEL OF A SOLID

In order to understand how rigidity affects the fact that a material reflects sound a lot or a little, go back to the example of pool. Imagine that all the coloured balls are linked by means of springs, as it was represented in the previous figure.

MATERIAL 1

MATERIAL 2
a) Taking into account that the springs drawn in material 2 are thicker than in material 1, which of the two materials would be more rigid?

b) If we suppose that the white ball collides with one of the coloured balls always with the same force, but this ball is linked to the rest of coloured balls by means of springs, which kind of material do you think will allow the white ball to bounce with more velocity, and with more energy? Why?

2.2.4. a) What does it mean in terms of internal structure the fact that a material is more rigid?

b) Think of an explanation about how the rigidity of a material affects its acoustic behaviour, that is, the fact that the material reflects sound a lot or a little, using the particulate model of matter.
**Attenuation by absorption: what are sound absorbers like inside?**

**Very porous or little porous materials**

A porous material has a solid structure (skeleton or fibres), which is generally dense and rigid, and numerous holes or spaces (called pores) in which there are air particles, which are interconnected between them if the pores are open. The following image shows the representation of a pore of a porous material. The rigid part is constituted by linked particles as in any other solid and the pores are spaces full of air particles.

![MODEL OF THE PORE OF A POROUS MATERIAL](image)

Observe the photographs of two different materials taken with a digital binocular magnifying glass. As you can notice, one material is very porous while the other has an even surface, without pores.

![MATERIAL 1](image) ![MATERIAL 2](image)

Remember that sound propagates when the particles of a medium vibrate and collide with each other transferring this vibration. When sound propagates through a porous material, it means that air particles inside the pores vibrate and that solid particles of the material vibrate as well.
2.2.5. How would you account for the fact that porosity of a material contributes to it behaving as a good sound absorber?

WHAT DOES SCIENCE TELL US?

As you have studied previously, sound absorbers are usually:

**Not very dense.** If a material is hardly dense, its particles can vibrate easily. For this reason, when sound waves reach a material which is not very dense, a great part of the energy of the sound is transmitted to the material, and little energy is reflected. Moreover, when sound propagates through the material part of the energy it is absorbed in making the particles of the material vibrate. Therefore, the more the particles of the material vibrate, the more energy of sound is absorbed.

**Not very rigid.** If a material is not very rigid, it could become deformed easily and, therefore, a great part of the energy of sound would be transmitted to the material. Again, the more the particles of the material vibrate, the more sound energy is absorbed.

**Porous.** In a porous material, sound propagates through the solid part and through the air that fills its pores. When airborne sound waves reach a porous material, a great part of their energy is transferred to the material because the waves can continue propagating through the air inside the (open) pores of the material, which are connected with the outside, without being reflected. The sound waves that propagate through the solid part of the material are partly reflected and partly they propagate through the material. As the sound waves that propagate inside the material find a lot of changes in the medium (from the solid part to the air or from the air to the solid), again they are partly reflected and partly continue propagating with less and less energy. Moreover, when air particles inside the pores vibrate to transmit sound, they rub and collide with the solid part of the material, absorbing that part of the energy of waves by heating the material a little.
2.2.6. In the previous box you have read a scientific explanation to account for how density, rigidity and porosity of materials affect the fact that these materials behave as good sound absorbers. Based on the previous explanation, explain how sound is attenuated in sound reflectors and how their physical properties make them behave like that (reflectors).

2.2.7. Interpreting experimental results based on the physical properties and the internal structure of materials

Comment on the following sentences using the model of sound reflector and absorber in terms of their internal structure and physical properties.

a) Porous materials such as glass wool are good sound absorbers

b) Dense and rigid materials such as chipboard with Formica behave as good sound reflectors
UNIT 3: ACOUSTIC CONDITIONING AND SOUNDPROOFING
In the previous activities you have learnt that there are two kinds of materials that are used to attenuate sound: sound reflectors and sound absorbers. Moreover, you have studied which physical properties and internal structure these materials have. These materials are available in the market and are used for **soundproofing** and **conditioning acoustically** a certain space (e.g., a recording studio, a room in a house, etc.).

### WHAT DOES SCIENCE TELL US?

**Soundproofing** a closed space implies insulating it acoustically from the outside, that is, avoiding that sound cannot enter the space, or leave it, therefore, avoiding noise pollution. Soundproofing (also called **sound insulation**) is referred to as techniques and technologies developed to insulate a certain space, that is, to attenuate the intensity level of the sound which enters or goes out. Therefore, all sound absorbers, sound reflectors or combinations of both materials are used to insulate sound. For this reason, these materials are generally called sound insulators.

On the other hand, **acoustic conditioning** works on improving the own acoustics of a closed space, that is, the sound quality inside the space. For this reason, it is necessary to control aspects such as the number of reflections of sound or the reverberation time. Although an ideal acoustics is not always possible to achieve, architects try to approach this idealization using certain techniques that make use of absorption or reflection properties of building materials and other objects or elements which could be put inside the closed space. In fact, some elements which could not seem very important, such as fitted carpets or curtains, are crucial and can change the acoustic conditions of a space. An appropriate acoustic conditioning implies controlling the reflections of waves in order to avoid undesired reverberations or echoes that can hinder understanding a conversation, for instance. The materials that are more used for conditioning acoustically are sound absorbers.
Design project: Which sound absorber would be more appropriate for the disco?

The DSR Company proposes to study how to soundproof the disco. Now it is your turn to think of a solution!

![Diagram of disco layout]

The aim of this project is to determine which material is a better sound absorber, among a set of materials available in specialized shops. You should be able to predict whether a material will behave as a good sound absorber analyzing its physical properties and, you also should determine empirically if it does. Furthermore, you should take into account other criteria in order to decide which material is more appropriate to soundproof the disco. In this way, you will reach a sound conclusion on the material which behaves as the best sound absorber for the requirements that are asked.
3.1.1. Now you are provided with some specific materials. Observe and manipulate them, and write down their properties (use the technical sheets of these materials to get more information about their density and porosity). You might also look on the Internet for other characteristics of these materials, which are commonly used in construction.

In this project you should decide which is the best sound absorber to attenuate sound that reaches the neighbours’ house from the disco. In order to choose the material to be used when soundproofing the disco, you should take into account different factors and therefore, you should analyze the problem according to criteria for selecting appropriate materials.
3.1.2. Physical properties
Since the engineers recommend using a good sound absorber, the material must have certain physical properties.

From the previous list of materials, which ones do you think would behave as the best sound absorbers? Justify your choice in terms of the physical properties of each material.

3.1.3. Experimental testing of the acoustic behaviour of materials
Once you have made your prediction, design and carry out an experiment to test to what extent each material behaves as a good or bad sound absorber. For this reason, you have to:
- Determine the acoustic behaviour of each material in order to distinguish the materials that behave as sound reflectors from those which behave as sound absorbers.
- Measure the attenuation produced by each material, in order to determine which material is the best sound absorber.

a) Design your experiment

   Explain the experiment(s) that you will perform to determine which material is the best sound absorber. Explain which magnitudes you will measure and how you will do it.
b) Experimental results

*Write down the results of your experiment using a table.*

---

c) Conclusions

*Which material has empirically behaved as the best sound absorber? Justify your answer.*

---

d) Compare your prediction with the experimental results.

---

3.1.4. In order to decide if you would use the material that empirically behaves as the best sound absorber in the disco, consider other criteria. Look for information on the Internet on these materials, if it is necessary. Think of the next aspects:

**Aesthetic qualities:** Will the material be put in the middle of plates of building material or is it going to be visible?

---

**Cost:** Is the chosen material cheap? Is the cost of a material a very important factor to decide the choice of the appropriate material to soundproof the disco?
Transport: Is it easy to get this material installed? Is it easy to transport?

Thermal insulation: Is it necessary that the material also has thermal properties?

Resistance to fire: Is it necessary that the material be fireproof? How important is this property?

3.1.5. Preparation of a report with your conclusions
Once you have reached a conclusion on the material which would be the most appropriate to soundproof the disco, write a report that collects all the information necessary to carry out the reform, justifying your proposal and explaining its advantages and disadvantages.
MATERIALS
SCIENCE PROJECT

UNIVERSITY-SCHOOL PARTNERSHIPS
FOR THE DESIGN AND IMPLEMENTATION
OF RESEARCH-BASED ICT-ENHANCED
MODULES ON MATERIAL PROPERTIES

ISBN 978-9963-689-33-0
2009