MODELLING AND INQUIRING SOUND ATTENUATION: DESIGN-BASED RESEARCH ABOUT AN ICT ENHANCED UNIT ON MATERIALS SCIENCE

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ABSTRACT
In this paper we present preliminary results of a design-based research about a teaching/learning unit on Sound Attenuation, which is part of a international research-based curriculum project on Materials Science. The common theoretical basis for curriculum design in 5 countries was focused on an inquiry-based and modelling approach and the use of ICTs to support it. In our project, a partnership of secondary school teachers and researchers has been established as a "learning community". During the curriculum design process this partnership has developed a conceptual clarification of sound attenuation in materials, a conceptual sequence and both teaching/learning and assessment tasks that reflect their views on inquiry, modelling and ICTs. Researchers have proposed theoretical issues for the pedagogical approach and supported and documented (through participatory observation) aspects of the implementation in real classroom settings. Different assessment activities have been used to analyse students' outcomes and some preliminary results regarding a model of sound attenuation in terms of energy are presented here. The idea of this analysis is to provide feedback for an iterative design-implementation-evaluation approach to curriculum development within a design-based research framework.

KEYWORDS
Sound attenuation, Acoustics, Materials Science, Inquiry, Modelling, ICT, MBL, Design-based research, Teachers' Community, Partnership.

INTRODUCTION

Brief introduction to the Materials Science Project

The Materials Science project[1] is an international research-based curriculum project on the topic of Materials Science funded by the EU[2]. The common theoretical basis for curriculum design in 5 countries was focused on an inquiry-based and modelling approach to teaching and learning science and the use of ICTs to support it. The main objective is to help secondary school students develop an awareness of the importance of Materials Science in society and their everyday life, with the aim of increasing students' interest in this topic or related fields. More information can be found in the project site[3].

CURRICULUM DEVELOPMENT ON ACOUSTIC PROPERTIES OF MATERIALS

The main aim of the Spanish group in the Materials Science project is the design of a teaching and learning sequence on *sound attenuation in materials* for 14-16 year-old students. Being part of the Materials Science project, this sequence deals with new content on this field and also introduces new

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[1] Materials Science is acronym for "University-school partnerships for the design and implementation of research-based ICT-enhanced modules on Material Properties".

[2] The project is funded under the DG Research, Science & Society, ref: S&S-16-042942.

[3] URL: http://lsg.ucy.ac.cy/MaterialsScience/

pedagogy, in particular an inquiring and modelling approach and the use of ICTs to promote it. In the following paragraphs our own approach to each of these innovations is detailed.

Conceptual understanding of sound attenuation and sound attenuating materials

Sound is a topic of physics that is present in most science syllabuses. Linking sound with the important everyday idea of noise pollution is also common in syllabuses with an STS or contextualised approach. Due to our purpose of giving a technological approach to the sequence and our attempt to introduce ideas of materials science in the current curriculum, we have chosen acoustic properties of materials, in particular those related to sound attenuation, as a focus of interest. With this purpose, we exposed the concept of sound attenuation to the process of "educational reconstruction" (Duit, Gropengießer and Kattmann 2005), using sources from diverse domains including engineering, material science and physics. This process led to the formulation of adequate conceptual models for secondary school students.

Modelling in sound attenuation

An important task for a scientist after having observed a phenomenon or process is to find an adequate explanation of it, either constructing a model or applying an existing one to justify what has been observed. In this sense, it is considered of great importance that students in the science classroom understand modelling and develop modelling competences. This would help them acquire knowledge about what science does and also to promote the building of conceptual models (Glynn and Duit 1995) and the capacity to make use of these models for exploring and predicting phenomena. The targeted conceptual models have to meet certain requirements. In particular, they should be able to (a) represent the defined aspects of the phenomenon, being possible to be refined or falsified; (b) provide a mechanistic interpretation of the underpinnings of (that aspect of) the phenomenon; (c) allow formulating predictions which can be put to experimental test (Constantinou 2007).

There are many definitions and views about modelling in the literature. Generally speaking, modelling is understood as a useful process that helps students build scientific knowledge and transfer it to many situations. There are two main views of modelling in the science classroom: building or using models as entities (material or virtual objects) and building and using *conceptual models*, understood as mental or cognitive representations of real world processes or things that students build in their mind in order to explain / interpret phenomena (Glynn and Duit 1995). The perspective taken here is that *conceptual models* are coherent units of structured knowledge used to organize factual information into coherent wholes and to represent observable patterns of natural phenomena.

Regarding sound attenuation, three main conceptual models are developed and introduced to students:

- a *model of sound attenuation based on energy terms*, to predict and explain how the energy associated to the sound wave is distributed when the sound arrives to a material regarding its acoustic behaviour.
- a *model of sound reflectors and sound absorbers in terms of their physical properties* to predict and explain how the sound behaves and is attenuated (by reflection or absorption) when it arrives to a material according to its physical properties. We focus on the properties of density, elasticity and porosity at the macroscopic level.
- a *model of sound reflectors and sound absorbers in terms of their internal structure* to predict and interpret how certain properties of a material influence its capacity of attenuating sound, using its microstructure.

The designed teaching / learning sequence is structured as an enchainment of purposeful activities intended to scaffold the process of modelling the role of sound absorbers and reflectors across those three models: from explaining and justifying sound attenuation in terms of energy to explaining and justifying it using both the physical properties (density, rigidity, porosity) or the internal structure of materials (See Annex 1, sequence of activities in block A, B and C).

Inquiring about sound attenuation

We consider that an effective engagement of students in modelling is the result of a motivating, meaningful and pedagogically rich scenario for the learning of science. According to the National Science Education Standards (2000), inquiry as a pedagogical approach provides the required pedagogically rich learning environment and, thus, should be emphasised as an adequate perspective to support students' learning of science.

Inquiry as a teaching and learning approach means engaging students in inquiring as a useful way for the learning of both the content of science and the way science functions and scientific knowledge is generated and justified, . The aim of inquiry as a pedagogical approach then, is that students get to understand the process of scientific inquiry and also get to use it for their own learning of science in the classroom.

To understand inquiry as a way of producing scientific knowledge and to use it to learn science, students have to master inquiry skills. We understand them in a broader manner than it is generally the case: as some scientific abilities, not only laboratory skills (such as measuring, reading graphs, etc) but also scientific competencies (controlling variables, using models, predicting, etc) necessary to productively engage in inquiry. In this sense, we consider that the essence of inquiry does not lie in labwork (hands-on inquiry) itself. It lies in the questioning, thinking, planning, reflecting, interacting, arguing, etc. that takes place when engaging in an investigation, that may or may not have an experimental component (minds-on inquiry).

Inquiry is usually triggered through good driving questions or problems to be solved. In our case, in order to make them meaningful for the students, we proposed to *contextualise* the scenario putting students in the situation of being the owners of a disco that needs to be soundproof and acoustically conditioned: reflection has to be increased in the dance floor while sound has to be attenuated in quiet areas so that it does not get outside. What sort of materials (with what properties) can do so is the main question that engages students in inquiring along the sequence.

Since the content of the sequence is already quite demanding, a pedagogical path of activities from a more guided inquiry to more open inquiry has been developed. First, students become familiar with the problem, the initial models to use, the laboratory instruments new to them (such as sound level meters), the experiments to be done, etc. with closely guided activities. Once students master an initial model of sound attenuation and both the use of instruments and protocols, an open inquiry is proposed to them to decide, from the data obtained, what the best material for solving the proposed problem is. For an overview of activities, see Annex 1.

ICT use in sound attenuation

The importance of the use of ICT for science education is broadly recognised. In our sequence, different sorts of ICTs have been used, taking into account their pedagogical potential and availability in our context.

Before the sequence is implemented, the use of the simulation *Simulason* (Vince and Tiberghien 2001) has been recommended to refresh or introduce, depending on the case, the concept of sound and sound wave to students.

For the implementation of the sequence, we have chosen MBL technology to capture data with sound sensors for the measurement of the attenuation produced by different materials The benefits of MBL technology have been largely discussed elsewhere (Pintó 2002). We have used MBL here because it allows registering and graphing in real time the evolution of sound intensity level measured with the sound level meter, which is the common instrument used in real life for noise control. These instruments allow comparison and discussion when testing different materials, which are tasks largely undertaken in the sequence (See Figure 1).

We have been able to use MBL both in guided and open inquiry experiments focusing on how to measure attenuation and how to differentiate sound reflectors from absorbers because both teachers and students in our context are familiar with this kind of technology.

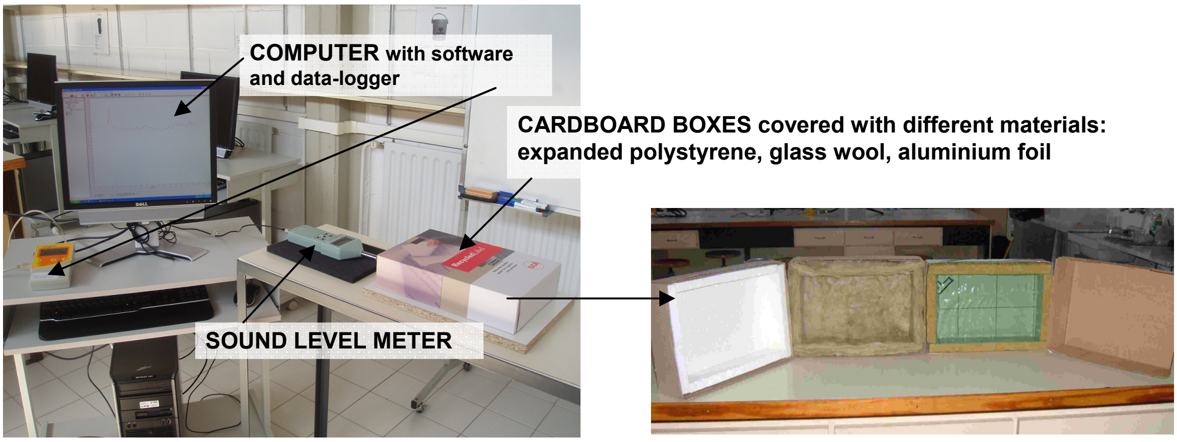

Figure 1. Description of the experimental setting. A sound source (a buzzer) is put inside a cardboard box covered with different materials. Sound intensity level is measured outside the box to measure sound attenuation and inside the box to determine the acoustic behaviour of the material.

Working on a School-University partnership
To teach the presented sequence is a highly demanding task for science teachers: it means to teach new content knowledge (interdisciplinary and highly technological such as materials science) with an inquiry and modelling approach and using different ICT. As some studies of curriculum reform processes have shown (Pintó 2005), a passive role for teachers in the planning and designing phases can have deep implications in the implementation, often distorting the rationale of the innovation in a critical way. In such cases, teachers lack the necessary sense of ownership as they are not emotionally involved in the innovation, (Andersson and Bach, 2005, Ogborn, 2002) and also they have not had the opportunity to learn enough about it, thus lacking the necessary knowledge. In this sense, the Materials Science project suggests strong university-school collaboration for the development of the sequences.

In order to design the Spanish sequence, a Local Working Group (LWG) of 7 science teachers[4] coming from 5 different secondary schools plus 3 university researchers was created. The group has worked in face-to-face meetings of 2 hours every fortnight and have collaborated actively also using an online platform (Moodle). Although teachers have been at the core of the design of the activities of the sequence, the initial planning, conceptual clarification and the introduction of pedagogical innovations (mainly the inquiry approach and the experimental setting) have been done by the university experts. Some purposeful sessions have been devoted to introduce these innovative ideas to teachers. The implementation phase has also been supported by external experts, who have observed some sessions during the classroom implementation of the sequence and have provided feedback that would be used to revise the sequence in a design-implementation-evaluation iterative process.

BRIEF DESCRIPTION OF SEQUENCE CONTENT AND STRUCTURE

The sequence "Acoustic properties of materials" has been structured in three main blocks, each with their own driving questions:
Block A: Sound wave – material interaction (5h)
- *What happens to sound in the disco?*

[4] In Spain science teachers have either a background on Physics (1 teachers in our group) or in Chemistry (6 teachers), but teach both subjects together in lower secondary.

- *How does sound propagate within the disco?*
- *What happens to sound when it finds an obstacle?*
- *Which conditions avoid that sound is heard outside the disco?*

Block B: Properties and internal structure of sound reflectors and sound absorbers (5h)
- *How can we test empirically if a material is sound absorber/ reflector?*
- *Which are the common physical properties of materials considered sound reflectors / absorbers?*
- *How can we explain the attenuation of sound in a material according to its internal structure?*

Block C: Acoustic conditioning and soundproofing (2h)
- *Which is the best sound absorber?*
- *Which are the best sound reflectors and more effective ways to condition and soundproof the disco?*

Annex 1 shows in detail the learning objectives and conceptual sequence of each of the blocks. It is also shown the sequence of activities designed to achieve these intended learning objectives.

RESEARCH APPROACH AND FIRST RESULTS

Once we had designed the sequence, we wondered to what extent it was effective to promote an appropriate students' understanding of the contents dealt within the sequence. The design-based research framework (Design-Based Research Collective 2003) precisely states that one of the requirements after having designed an innovation is to carry out a research study on its effectiveness through continuous cycles of design, analysis, evaluation and redesign. Effectiveness refers to the extent that the experiences and outcomes of an intervention are consistent with the intended objectives. Our aim is to evaluate the effectiveness of the designed sequence through analysing students' learning outcomes.

In order to make an in-depth evaluation of the sequence, the learning outcomes[5] achieved by the students have to be confronted with the expected learning objectives[6]. For the Acoustics sequence, a set of learning objectives were formulated by the researchers and agreed by the teachers. Before the implementation, teachers specified the learning objectives they would be focusing on, according to the characteristics of the students' group.

Data for the evaluation of the whole sequence were obtained from:
- *teachers involved in the design and the implementation through:*
  a) the *"implementation worksheets"* that each teacher filled for each activity describing his/her perception of different aspects of their implementation.
  b) the *students' worksheets to* obtain information on students' understanding of some specific points of the conceptual content.
  c) the *results of the conceptual test* from all the students. Each question of this students' evaluation instrument is related with some specific learning objectives. A common students' evaluation instrument was developed by all the members of the LWG, and each teacher selected the questions s/he wanted to use according to the learning objectives intended to address with her/his group.
- *the researchers using two instruments:*
  a) the set of *"Learning targets"* intended to be achieved for each group of students.
  b) the *Class Observation grid,* for the field notes taken during the implementation process by external experts and by participating researchers, specially referring to the ways of adjusting the sequence so as to become functional in real classrooms and to accommodate teachers' concerns.

[5] We reserve the term "learning outcome" to mean what is actually learnt by the students as a result of the implementation of the sequence.
[6] Through the learning targets, we describe what the intended students' learning achievements are and are expressed in a very specific and measurable format.

Preliminary research study on effectiveness of the sequence

In this paper, we present briefly a preliminary research to show the procedure we carry out for studying the effectiveness of the sequence. In this example, we analyse students' understanding of a specific conceptual content: the model of sound attenuation in terms of energy, already mentioned.

Specifically, the question that we are intended to answer is: *To what extent the sequence on Acoustic Properties of Materials is effective in promoting the students' building of the conceptual model sound attenuation in terms of energy?*

We analyse the level of comprehension of the energy model achieved by two groups of 15-16 year-old students (sample n_1=22 and n_2=14) who participated in the implementation of the designed sequence with their teachers, who were members of the LWG. Both teachers had more than 20 years of teaching experience and their background was predominantly in Chemistry.

For such study we only used three of the above instruments: the set of learning objectives related to these contents, the piece of the students' worksheets referring to these conceptual contents and the question of the conceptual test referring to the corresponding learning objectives. The analysis of the data was intended to evaluate the extent to which students achieved the learning objectives concerning the interpretation of sound attenuation in terms of energy. These learning targets can be phrased as:

- Students should be able to apply the principle of energy conservation when expressing that the energy of an incident sound wave in an interface is distributed among energy of reflected sound, energy of transmitted sound and absorbed energy inside the material (*LT10*).
- Students should be able to express and apply in different contexts the diagram that describes that an incident sound on an interface is partly reflected, partly absorbed and partly transmitted through a material (*LT11*).
- Students should be able to distinguish a sound absorber from a sound reflector according to their acoustic behaviour (*LT15*).

This study is not intended to compare different teaching strategies or designed materials to promote students' learning of certain contents. However, the main aim of this study, as it has been said, is to test the effectiveness of the sequence in relation to the initial objectives. Therefore, we adopt a different methodological approach, sometimes called "internal evaluation", to compare students' outcomes with those obtained by the same students before or at the beginning of the sequence. With this approach, we analysed the extent to which students understood the content related to sound attenuation, starting from their own ideas and having participated in the classroom implementation of the sequence.

Below, we describe the starting point of teachers and students. Next, we describe the classroom implementation (or "inputs") and the instruments of data collection. Finally, we present and discuss results on students' understanding of sound attenuation (or "outputs").

Starting points

Teachers expressed their intention that all or almost all of their students achieved these learning objectives (*LT10*, *LT11*, and *LT15).*

What is the starting point of students?

At the beginning of the unit that dealt with the topic of sound attenuation in materials, students were asked a question in order to explore their initial ideas about this topic. A preliminary task was included in students' worksheets, in which they had to interpret some data relating to intensity levels of emitted and transmitted sound. Students not only had to calculate sound attenuation but they were also asked what had happened to the proportion of sound that had not been transmitted to the other side of a wall. 50% of the students (18/36) recognized that reflection of sound is one of the phenomena associated to sound attenuation:

[Sound that has not been transmitted through the wall] has been reflected inside the disco

8% of students (3/36) recognized absorption as the phenomenon associated to sound attenuation. 31% of students (11/36) considered that both phenomena (reflection and absorption) contribute to sound attenuation. The remaining 11% of students did not answer this question. Therefore, most of the students of this sample (81%) started this sequence with the idea that sound attenuation in a material surface is due to the reflection of sound on it. Fewer students (39%) seemed to be aware that absorption is also a phenomenon which intervenes in sound attenuation.

Inputs

What information was provided to students and what tasks they carried out before the analysed questions?

After exploring students' previous ideas around sound attenuation, students read and discussed a piece of information that explains how energy of an incident sound wave is distributed when interacting with a material:

1. This text introduces a formal definition of attenuation of sound in a material object as the difference of sound intensity level at each side of the material (incident and transmitted sound).
2. The text explains that sound intensity and energy associated to sound waves were related concepts.
3. It also gives an explanation of the phenomena that take place when sound is attenuated in terms of reflection and absorption.
4. Moreover, students analyzed sound attenuation using two different representations: equations and images.
   - Equations allow synthesizing the idea that the energy associated to reflected sound and the energy absorbed inside a material could be considered the part of sound that is not transmitted to the other side of the material. That is, the "attenuated energy" corresponds to the sum of both components.

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

   - The visual representation used to promote students' understanding on sound attenuation is composed by lines and dots representing incident, reflected, absorbed and transmitted energy. The area of the parallelogram represents the amount of energy associated and it is intended to convey the idea that the total incident energy is conserved. Figure 2 is the visual way to introduce the model for interpreting sound attenuation in energy terms.

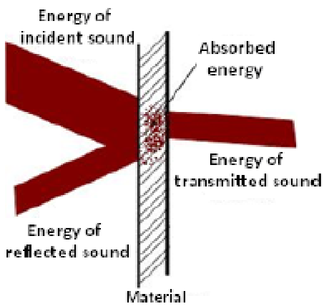

Figure 2. Representation of the sound wave-material interaction in terms of energy

Obviously, this model has some limitations and risks: it can lead to a substance-based view about energy, it can induce to the idea of sound ray as a real and localised object, it could be interpreted as if the distribution of energy were the same as the path of sound waves, a direction of propagation, etc. Nevertheless, despite the possible misleading issues we still believe that this representation can effectively convey the idea of energy distribution.

Data collection

Students were confronted with certain questions during and after the implementation of the activity sequence so as to assess the progress of their ideas on this topic. In this paper, we focus on two of these questions. The first was included in the students' worksheets (*Figure* 3), while the latter was part of the conceptual test that was completed by students s (*Figure* 4). This test was administered 2-3 weeks after students had completed the worksheet question (Figure 3).

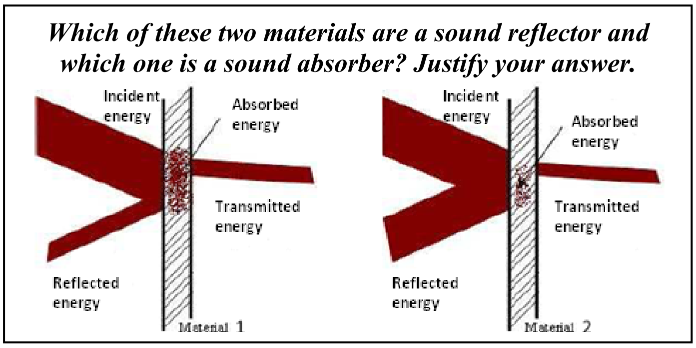

Figure 3. Question in students' worksheets

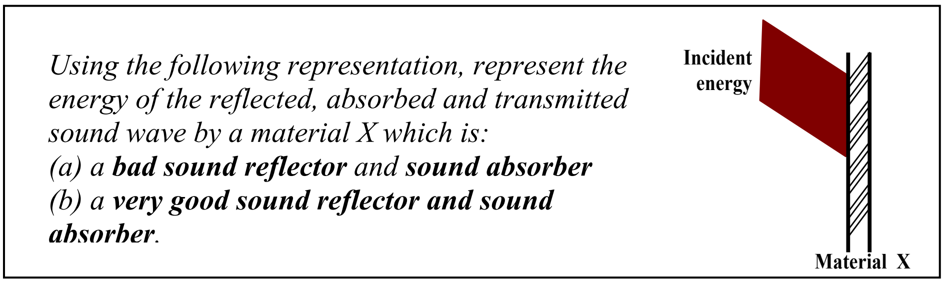

Figure 4. Question in students' exams

Outputs

Results from the students' responses to the question in the worksheets

Here we present the students' answers to the worksheet question where they had to distinguish between two different representations of energy distribution (see Figure 3). These students' responses have been analysed and categorized using a systemic network (Figure 5). The main categories or subcategories correspond to the learning outcomes.

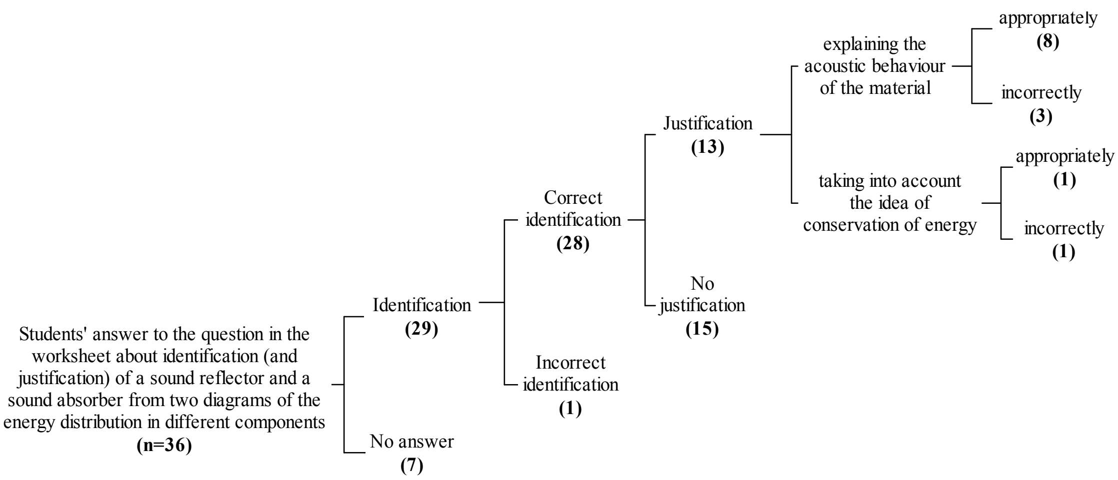

Figure 5. Analysis of students' answers to the question in the worksheets

The analysis of the worksheets showed that most of the students (29/36) answered the question while fewer students (7/36) gave vague answers or did not fill in their worksheets. Almost all students (except one) identified correctly the sound reflector and the sound absorber with the respective diagrams showing the distribution of energy when a sound wave interacts with a material.

We also found that approximately half of the students who answered correctly that question (13/28) justified their response whereas the rest (15/28), despite being able to correctly identify the materials, did not know how to express their view and did not write any comment justifying it. Most of the students who justified their answer (11/36) did it in terms of the acoustic behaviour of the specific material:

> *"Material 1 is the sound absorber because the greatest part of the energy has been absorbed by the material. Material 2 is the sound reflector because the greatest part of the energy has been reflected and less energy has been absorbed"*

Apart from the students who justified their answers in terms of the acoustic behaviour of materials, two students (2/36) tried to apply the principle of energy conservation. They reflected the idea that the incident energy has to be the same as the sum of the reflected, absorbed and transmitted energy. Only one gave a correct justification.

> *"Material 1 is a sound absorber because the transmitted energy plus the reflected energy is not the same as the incident energy; therefore a great part of the energy has been absorbed by the wall. Material 2 is a sound reflector because the transmitted energy plus the reflected energy is almost the same as the incident energy and very little energy has been absorbed by the wall"*

In definitive, during the period of classes devoted to characterise materials according to their acoustic behaviour and to build a conceptual model of sound attenuation in terms of energy, a large percentage of students (80%) were able to identify correctly which material is a sound reflector and which one is a sound absorber. However, only 25% (9/36) were able to justify it writing a correct argument.

Results from students' responses to the exam question

In the exam that was administered to students some weeks later, students were asked to represent the energy of the reflected, absorbed and transmitted sound wave by a material X which is *a) not a very good sound reflector and sound absorber, or b) a very good sound reflector and very good sound absorber.* Students' task in this question is more demanding compared to the previous one (worksheet task) since they are asked to draw a graphical representation themselves rather than to interpret a given graphical representation.

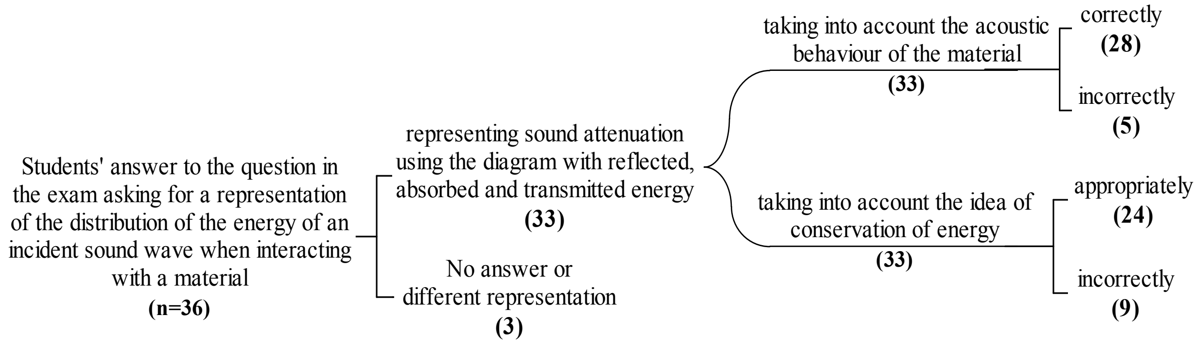

Figure 6. Analysis of students' answers to question 2 in the exam

Students' responses could be analyzed across different dimensions. We found that most of the students (33/36) were able to represent the different components of the energy of sound waves when it interacts with a material using parallelograms and dots inside the material (Figure 7 and 8). In addition to this, many of them (28/36) were able to distinguishing correctly whether the material was a sound reflector, a sound absorber or neither.

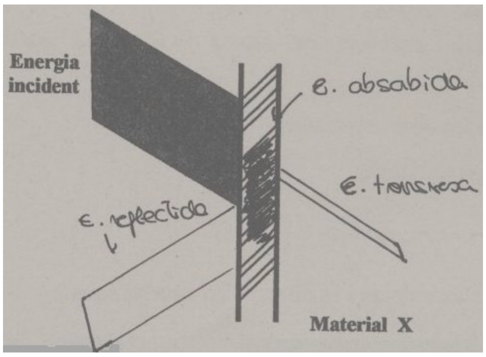

Figure 7

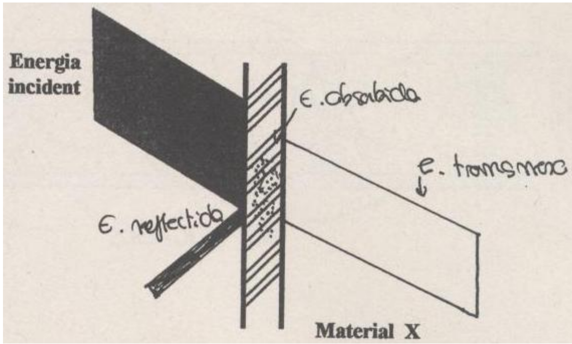

Figure 8

We can look at the data focusing on another dimension. In the conceptual test, we found that 24/36 (a large percentage of) students took the "perspective of energy conservation". They made representations where it was qualitatively suggested that the amount of energy associated with the incident sound is the sum of parallelograms corresponding to the reflected, transmitted and absorbed energy, therefore, differentiating if the material is very good or very low sound reflector or sound absorber.

Nevertheless, some difficulties were also identified in some students' answers. For instance, very few students did not represent the absorbed energy (Figure 9) but only the reflected and transmitted sound waves. Some other students drew the same amount of energy associated to reflected sound (or absorbed energy) in the case of materials which are good sound reflectors (absorbers) and in the case of bad sound reflectors (absorbers). Students that could not draw, in a right way (5/36), a reflector or absorber material were able (within the 9/36) to correctly represent the distribution of energy when sound interacts with the material. We can interpret this as an indication that students either do not appreciate the meaning of the visual representation or do not understand energy conservation.

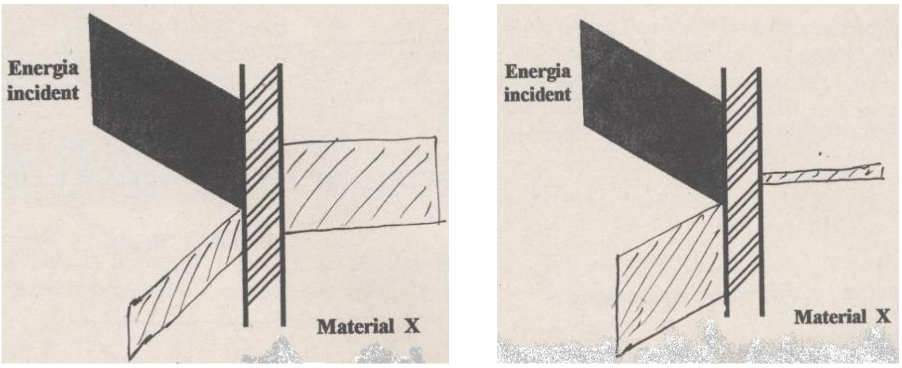

Figure 9. Student's response to question 2 in the exam.

Linking the results from students' responses collected with both instruments

Regarding the students' starting point, the learning objectives to be achieved and the answers to the questions obtained with the two instruments (see above), we can conclude that:

- Most of the students (77% in both cases) have been able to distinguish a sound absorbing material from a sound reflector according to how they behave in relation to sound attenuation (*LT15*) in two different tasks: interpreting a visual representation (worksheet) and drawing a visual representation (exam). Initially, only 39% of students recognized the role of the absorption in the attenuation and 81% of them the role of the reflection. That means that initially most of the students were able to easily recognise the existence of sound reflectors but few of them recognized the existence of sound absorbers. Therefore, we can infer that, as far as the learning objective *LT15* is concerned, the implementation of the sequence has been successful.

- In the exams, a significant part of students (24/36) represented appropriately the diagram that describes the distribution of energy of an incident wave, considering the reflected, the absorbed and the transmitted component of the energy (*LT11*). Thus, despite the limitations of the chosen visual model of energy distribution, most of the students were able to apply correctly this model to explain the distribution of energy when sound interacts with materials that behave in a different acoustic way (e.g., bad sound reflector and sound absorber, very good sound reflector and sound absorber). Therefore, we consider the visual model satisfactory enough to accomplish our purposes.
- Students also applied correctly the principle of energy conservation (*LT10*) by representing qualitatively the different components of the energy of the incident wave. During the implementation, only two students took into account the energy conservation when answering the question of the worksheet. These different results in the students' answers could be possibly attributed to the fact that students were more able to express their views by using a graphical representation than by elaborating a written justification. An alternative interpretation is that in completing the conceptual test students had more opportunities to reflect and assimilate the taught ideas. In any case, further research is needed to determine the variables that could affect these different results.

In conclusion, data analysis suggests that almost 70% of the students in our sample were able to achieve the intended learning objectives (*LT10*, *LT11*, *LT15*) using the activity sequence as it was implemented by two teachers of the LWG. However, some difficulties and limitations were revealed by this study and they will be taken into account for refining the sequence or suggesting different teaching strategies in order to improve students' learning.

CONCLUSIONS AND FUTURE RESEARCH

This piece of research has demonstrated the analysis that we have carried out to illustrate the process of evaluating the effectiveness of the designed sequence according to students' outcomes with regard to some specific learning objectives. We could argue that students' outcomes in relation to the model of sound attenuation in terms of energy are quite positive since they suggest a significant improvement with respect to the starting points and the learning objectives that were pursued. Therefore, we can say that the visual model or representation has turned out to be satisfactory enough according to the purposes of the sequence.

Nevertheless, our results also suggest some kinds of limitations or difficulties that impede students' effort to achieve certain learning objectives. For instance, the different results in the students' answers between the two questions that were discussed in this paper can be interpreted in terms of students' abilities. We could say that students are more able to express their views by using a graphical representation than by elaborating a written justification. For this reason, we have decided to refine the sequence and to propose some changes of teaching strategies, which are aimed to reinforce the argumentation skills of students (with some changes in the worksheet format and with the provision of guidelines to teachers on how to encourage students to provide arguments and how to scaffold them in this respect). Furthermore, we consider that the issue of energy conservation should be explicitly addressed as part of the sequence since some students did not take it into account in their worksheets or the exam.

The main aim of the Material Science project is not only to generate a detailed description of what is learnt and what is not in each sequence. We are also interested in analysing the characteristics of the sequence that should be modified and how in order to improve students' achievements. In this sense, we will take into account the results from this research on students' outcomes so as to refine the sequence in an iterative process. In this way, a refined product that is a research-based designed material for science classes will be obtained.

Other questions from students' worksheets and exams regarding other conceptual models dealt with in the sequence are being analysed. In future analysis, also other variables could be taken into account, particularly students' motivation, classroom teaching strategies, etc. The involvement in a large project as the Material Science allows getting multiple sources of data at National and European level, from both the class environments and the LGW group. It is expected that the results of these research studies will lead to efficient sequences and fruitful methodological approaches.

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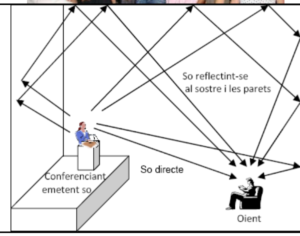
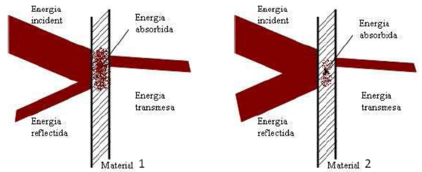
ANNEX 1: DESCRIPTION OF THE SEQUENCE ON ACOUSTIC PROPERTIES OF MATERIALS

<table>
<tr><th colspan="4">BLOC A: SOUND WAVE – MATERIAL INTERACTION (max. 5h class)</th></tr>
<tr><th>LEARNING OBJECTIVES[7]</th><th>(CONCEPTUAL) CONTENT SEQUENCE</th><th colspan="2">SEQUENCE OF ACTIVITIES</th></tr>
<tr>
<td rowspan="5">Conceptual learning objectives:
• Understand, apply and transfer to different situations the concepts of this block

Procedural learning objectives:
• Explain phenomena by giving arguments
• Read and interpret images
• Represent directions of propagation of sound
• Use scientific vocabulary</td>
<td rowspan="5">Some phenomena related to sound wave - material interaction:
• Reflection
• Diffraction

Explanation of sound wave - material interactions in terms of the conservation of energy:
• Energy of the incident wave
• Energy of the reflected wave
• Absorbed energy
• Energy of the transmitted wave

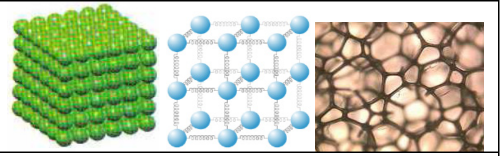
Effects of the sound wave - material interaction
• Attenuation of sound

Types of materials depending on their acoustic behaviour:
• Sound reflectors
• Sound absorbers</td>
<td>Activity 1: The acoustic problems of a disco
Introduction to the context of the sequence and exposition of the general problem about insulation and conditioning of a disco, which has to be solved throughout the sequence.</td>
<td></td>
</tr>
<tr>
<td>Activity 2: How does sound arrive at all the places of a disco?
Study of the sound reflection phenomenon (direction of propagation of the reflected sound wave, sound path) and study of some effects (such as reverberation) and some applications (such as sonar).</td>
<td rowspan="2">
</td>
</tr>
<tr>
<td>Activity 3: What happens to sound when it finds an obstacle?
Study of the sound diffraction phenomenon when it finds an obstacle in its path.</td>
</tr>
<tr>
<td>Activity 4: Which environmental conditions achieve that we can not hear noise outside of a disco?
Study of sound attenuation through a material in terms of energy. Distinction between sound reflectors and sound absorbers depending on their acoustic behaviour.</td>
<td>
</td>
</tr>
<tr>
<td colspan="2">Activity 5: Synthesis activity
Organization of the contents / concepts using a conceptual map.</td>
</tr>
</table>

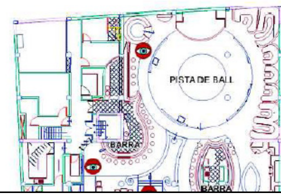
<table>
<tr><th colspan="3">BLOC B: PROPERTIES AND INTERNAL STRUCTURE OF SOUND REFLECTORS AND SOUND ABSORBERS (max. 5h class)</th></tr>
<tr><th>LEARNING OBJECTIVES</th><th>(CONCEPTUAL) CONTENT SEQUENCE</th><th>SEQUENCE OF ACTIVITIES</th></tr>
<tr>
<td rowspan="2">Conceptual learning objectives:
• Understand, apply and transfer to different situations the concepts of this bloc</td>
<td rowspan="2"><u>Model of sound absorber</u>
Properties of sound absorbers:
• Low elasticity (low stiffness)
• Low density
• Porosity</td>
<td>Activity 1: Which characteristics does a material have to be considered a sound reflector / sound absorber?
Guided inquiry activity. Students start from that general question, which is related to the context of the sequence (problem of noise pollution because of a disco), and do different tasks in order to answer to the question.</td>
</tr>
<tr>
<td>Activity 1.1: Collection of students' preconceptions about the characteristics of materials that are considered sound reflectors or sound absorbers. The aim of this activity is the construction of a model of sound absorber and sound reflector agreed by all the class.</td>
</tr>
</table>

[7] Trough the learning objectives we describe the purposes of the module.

<table>
<tr><td rowspan="6">Procedural learning objectives:
• Explain phenomena by using the model developed throughout the sequence
• Read tables of data and interpret graphs
• Use an experimental setting (equipment and sensor) to collect data
• Design experiments, controlling variables
• Represent the internal structure of a material</td><td rowspan="6"><u>Model of sound reflector</u>
Properties of sound reflectors:
• High elasticity (rigid)
• High density
• No porosity

<u>Microscopic model</u> that allows explain the relations between the properties of the materials (elasticity, density and porosity) and their acoustic behaviour.
• Attenuation by reflection
• Attenuation by absorption</td><td>Activity 1.2: How can we measure sound?
Activity in which students have to make themselves familiar with the equipment used to collect data of the sound intensity level (sound level meter, data-logger Multilog and software Multilab) and with the graphs and tables of data provided by the software.</td><td></td></tr>
<tr><td>Activity 1.3: How can we test empirically whether a material is sound absorber or sound reflector?
Students have to design an experiment in order analyze whether a certain material behaves as a sound reflector or as a sound absorber.</td><td rowspan="2"></td></tr>
<tr><td>Activity 1.4: Are these materials good sound absorbers or sound reflectors?
Empirical testing of the acoustic behaviour of certain materials.</td></tr>
<tr><td colspan="2">Activity 1.5: How can we describe sound attenuators? Which properties do they have?
Characterization of the previous materials depending on their properties (density and stiffness) and their internal structure (porosity). Relation of these characteristics with the acoustic behaviour of the materials.</td></tr>
<tr><td>Activity 2: How can we explain the attenuation of sound in a material according to its internal structure?
Construction of a microscopic model of a sound reflector and a sound absorber to interpret its acoustic behaviour depending on its internal structure.</td><td></td></tr>
<tr><td colspan="2">Activity 3: Synthesis activity
Organization of the contents / concepts using a conceptual map.</td></tr>
</table>

<table>
<tr><th colspan="4">BLOC C: ACOUSTIC CONDITIONING AND ACOUSTIC INSULATION (max. 2h class)</th></tr>
<tr><th>LEARNING OBJECTIVES</th><th>(CONCEPTUAL) CONTENT SEQUENCE</th><th colspan="2">SEQUENCE OF ACTIVITIES</th></tr>
<tr><td>Conceptual learning objectives:
• Understand, apply and transfer to different situations the concepts of all the sequence

Procedural learning objectives:
• Describe materials</td><td><u>Acoustic conditioning</u>:
Uniform diffusion of sound and reduction of the reflected sound in all the places of a room to improve sonority and acoustic comfort.</td><td>Activity 1: Which materials can we use to protect ourselves from sound? Open - inquiry activity. Students have to design a research in groups in order to come to a conclusion about which material can be a good sound absorber that allows attenuate the noise that comes from a disco to a house.</td><td></td></tr>
</table>

• Design an experiment in order to test a prediction • Explain phenomena by giving arguments • Read and interpret images • Summarize information and establish conclusions • Propose appropriate solutions for a problem related to the context of the sequence	*Acoustic insulation*: Protection of a room in order that the sound does not come in. Therefore, reduction of noise that reaches the receptor through an obstacle (minimum transmitted energy).	*Activity 2: Project of acoustic conditioning of a disco* Writing a group report that gathers information needed to make a project of acoustic conditioning of different spaces of a disco in order to achieve the best acoustic conditions for each space.	