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## Open access online course in acoustics in the frame of AcouStics Knowledge alliance (ASKnow) project

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In most engineering courses, acoustics is only taught to a very limited extent. As a result, engineers often do not have sufficient knowledge when they have to solve problems in which acoustics plays a role. The Acoucou.org courseware platform aims to solve a part of this problem by offering freely accessible online courses that can be used for formal education and lifelong learning. The European project ASKnow, funded by the European Commission's Education and Culture Executive Agency, aims to offer five new, freely accessible online courses on the acoucou.org platform. The five courses are: fundamental acoustics, psychoacoustics, acoustic simulations and auralization, electroacoustics, and room and building acoustics. Each course consists of thirty lessons and two case studies. For each lesson, the theoretical part is complemented by an interactive part to promote the user's acquisition of the different concepts and by an assessment part to check the knowledge acquisition. The consortium, composed of academic and business institutions, is first introduced. Then the methods and tools for designing the courses are presented in detail. Finally, examples of implementation are presented. The difficulties associated with international cooperation in times of a pandemic are also discussed.

## 1 Introduction

Acoustics is everywhere in our lives, from the audible to the inaudible, and has applications in all sectors of activity, such as transportation, entertainment, telecommunications, construction, health, consumer electronics, etc. However, higher education programs entirely devoted to acoustics are rather rare. This means that people working in the various sectors of activity are often not sufficiently aware or trained in acoustics and their work may be negatively affected.

With this in mind, a consortium gathered around KFB Acoustics, a Polish company, to create free online educational resources on the <https://acoucou.org> website. E-learning has grown significantly over the past two decades and offers many benefits [1, 2, 3] such as better learner engagement, availability of hands-on resources, allowing practical experiences and enhancement of concept analysis, personalized learning schedule, etc. Online educational resources are therefore a very good candidate to fill the knowledge gap in acoustics.

Among the outcomes in the frame of Acoucou environment, the ArAc Multibook, a free interactive acoustics book for architects has first been released. It was then followed by two online courses: Acoustics for Engineers (ACE) and Acoustics for Industry (ACI). ACE is an interactive web-based engineering course with a simulator module to increase practical skills. It is aimed at specialists from the machinery, automotive and rail industries. ACI is a visual introduction to industrial acoustics including noise in environment and industry, impact of noise on human health and noise management.

In order to make an addition to the panel of courses offered by the Acoucou platform, a project proposal was submitted to the European Education and Culture Executive Agency (EACEA) within the Key Action2: Knowledge Alliances of the ERASMUS+ programme. The proposed ASKnow project (<https://asknow.acoucou.org>) has been chosen for funding and it started on the 1st of January 2020.

The objectives of the project and the work done so far are presented in this paper. Section 2 introduces the ASKnow project by presenting its consortium and the expected outcomes. Section 3 focuses on the implementation of the project, while Section 4 presents the reviewing process.

Finally, some concluding remarks are given and perspectives of dissemination are proposed.

## 2 The ASKnow Project

### 2.1 Consortium

The ASKnow project is led by a consortium that consists of four universities and four companies:

- Le Mans Université, France,
- KU Leuven, Belgium,
- RWTH Aachen, Germany,
- University of Zagreb, Croatia,
- KFB Acoustics, Poland,
- HEAD acoustics, Germany,
- Jazzy Innovations, Poland,
- Kahle Acoustics, Belgium.

Among the companies, three are specialized in acoustics, while the core business of Jazzy Innovation consists of the development of web and mobile applications. In addition to eight full partners, the ASKnow consortium also involves 14 associated partners who contribute to the implementation of specific project tasks or support the dissemination and sustainability of the project outcomes. These associated partners represent different types of organizations:

- **Non-Governmental associations:** the Audio Engineering Society – AES (USA) & the European Acoustic Association – EAA (Spain),
- **Higher Education Institutions:** The Slovak University of Technology in Bratislava – STU (Slovakia) & the Graduate School of Engineering EPF (France),
- **Small & medium enterprises:** e.GO Mobile AG (Germany), Harmonia Acústica (Brazil) & R&D Team (Germany),
- **Large enterprises:** DOLBY Poland, I.G. Bauherhin GmbH (Germany), Miele & Cie (Germany), PSA Group (France), STIHL AG (Germany), SOMFY (France) & ZIEHL-ABEGG SE (Germany).

Together, the partners form a consortium that will develop five new courses to be added to the Acoucou platform.

## 2.2 Project outcomes

The main objective of the ASKnow project is to provide interactive, work-based and open-access knowledge on acoustics to several target groups: students, teachers in higher education institutions, professionals, and corporate researchers, with the goal of increasing their skills and awareness of the leading role of acoustics in several fields. To this end, five topics of interest have been chosen: acoustic fundamentals, psychoacoustics, acoustic simulations & auralization, electroacoustics, and room and building acoustics, each of them to be covered by one course. These topics have been chosen to complement existing courses (ArAc, ACI and ACE), while taking into account the consortium's areas of expertise and real-world concerns. The content of each course is described in the following subsections.

## 2.3 Acoustic fundamentals

For this fundamentals of acoustics course, it was decided to treat the topic in more depth than for the other four courses of the ASKnow project. Indeed, the basics of acoustics had already been presented in the ACE and ACI courses already implemented on the Acoucou website. First of all, the different concepts (basic equations of acoustics, wave equation, reflection, transmission, acoustic impedance, etc.) are presented within the framework of a one-dimensional theory (only one space variable) thus introducing the concept of plane waves. Then, the propagation of plane waves is extended to 3 dimensions allowing to approach the Snell-Descartes laws. Afterwards, different models of sound sources are presented (monopole, dipole, quadrupole) before discussing the solutions of the wave equation in spherical coordinates. Then, the concepts of radiation and diffraction are introduced. The next four lessons are dedicated to the propagation of sound in waveguides and cavities, leading to the definition of higher modes. To finish this course, nine lessons focus on particular notions such as dB scale, image sources, dispersion, group and phase velocity, dissipation, surface impedance of materials, matrix formalism for waveguides, horns, etc.

## 2.4 Psychoacoustics

The second course is dedicated to psychoacoustics. It begins with a chapter on the human perception of sound and includes topics such as the anatomy of the ear, the processing of sound by humans, the critical bands, masking effects and hearing threshold. The second chapter deals with psychoacoustic parameters that aim at quantifying human perception of sound such as loudness, roughness & fluctuation strength, tonality and sharpness. The advantages of binaural hearing are then presented and the mechanisms behind binaural sound source localization are explained, leading into a lesson on the Head Related Transfer Functions

(HRTF). The concept of human auditory modelling is then demonstrated by means of two exemplary hearing models. Furthermore, the technology behind binaural recording and playback, including the required corrections for binaural signal analysis and reproduction, is introduced. The next part concerns speech intelligibility starting from speech production to the assessment of speech intelligibility. Then listening experiments are introduced from their design to their statistical evaluation and their application to the evaluation of sound system quality. Finally, further perceptual topics are introduced such as the perception of space, soundscapes, the perceptual evaluation of noise and auditory illusions.

## 2.5 Acoustic simulations & auralization

The third course concerns acoustic simulations & auralization. First, the scientific principles of basic signal processing are recalled (impulse responses, convolution, Fourier transform and discrete calculations). The next course chapter deals with room acoustic simulation and introduces different modeling techniques such as image source models, ray tracing simulation, radiosity methods and wave-based models. The prediction of a room reverberation time is also discussed. The third part concerns modeling methods for noise control and sound design. This is where topics such as environmental sound propagation, airborne sound in buildings, impact sound in buildings and binaural transfer path analysis are described. An interesting feature is the possibility to listen the outputs of the simulation, this operation is called auralization and is the subject of the next chapter in which the usual methods are described. Auralization can be performed using several rendering systems, such as headphones, binaural loudspeaker set-ups, stereo & Vector-Base-Amplitude Panning (VBAP), panning techniques using object-based audio and Ambisonics. These methods are described in the fifth part of this course. Finally, some applications of acoustic simulations are presented before concluding with their perceptual evaluation.

## 2.6 Electroacoustics

For this course on electroacoustics, a presentation of the basic knowledge in electricity, mechanics and acoustics necessary to understand the behavior of audio systems is first made. Then, the linear and non-linear characteristics of transducers are presented. Following this, the principles of transduction such as electrodynamic and electrostatic coupling are introduced. The mechanical-acoustic coupling by membrane is also explained. Based on this knowledge, theoretical models of sensors (geophones, and microphones) or sound sources (shakers and loudspeakers) are detailed and illustrated. Particular attention is paid to directive microphones and to the Thiele and Small parameters characterizing the moving-coil speaker. Four lessons are then dedicated to the behavior of loudspeaker systems and their acoustic load (closed cabinet, bass reflex, passive radiator, etc.). The filtering of multichannel speakers is also introduced. After these fairly accessible lessons, more

advanced knowledge is offered starting with advanced characterization of loudspeaker drivers. The course ends with four lessons dedicated to systems using a large number of transducers: microphone arrays or loudspeaker clusters. Several applications such as line-array systems, multichannel 2D or 3D audio systems and sound zones principle are presented.

## 2.7 Room and building acoustics

The course is divided into two chapters entitled room acoustics and building acoustics, although certain lessons have been developed to expand this basic concept. An introductory lesson explains the difference between these two fields. The first 15 lessons are devoted to room acoustics. The theoretical aspects of sound propagation in rooms, the effect of room geometry and the role of acoustic treatments are presented. The interaction of general sound sources as well as loudspeakers with a room is also introduced. The design of rooms is also discussed by presenting general requirements, and objective and subjective parameters which can be used to define design criteria. The focus is also made on spaces for speech (single speaker and multi-speaker environments) and spaces for music. The building acoustics part of the course also consists of 15 lessons. It starts by introducing different type of noise sources (airborne or impact) as well as common types of sound transmission through building structures (direct or flanking) and the associated metrics. Different types of elements are also addressed (single and double-leaf walls, floors ceilings, facades, doors and windows). The course continues with the measurement methods used for the quantification of sound insulation performance and a possible way of acoustic classification of sound insulation. The final part of the course deals with more applied matters such as the design criteria and common practices. Special attention is given to practice approaches in the design of innovative, sustainable and cost-effective buildings. Background noise sources and vibration isolation are also addressed.

## 2.8 Practical cases

For each course, two practical cases have also been developed. These allow the user to apply the concepts learned during the course to concrete and applied topics and thus solidify their knowledge. Among others, the following practical cases have been developed: Acoustic simulation of a car using binaural transfer path synthesis, psychoacoustical listening experiment examining our ability to localize sound sources, design of a two-way loudspeaker system, performing a sound quality evaluation study, etc.

# 3 Implementation

## 3.1 Course Structure

Each course is divided into thirty lessons. Each lesson is further divided into three parts, labeled A through C:

- **Part A** or theory section which introduces and presents the scientific concepts. Compared to a classical course that would be followed at the university, the length, the language and the level of difficulty have been adapted to reading on screen.
- **Part B** or principle section is dedicated to the illustration of the principles stated in part A. Different formats are used here: videos, sounds, dynamic applets in which the results are modified according to user settings (see Figure 1). Each part B requires the learner's participation: scrolling through the slides, playing videos or sounds corresponding to different options, modifying the parameters of a model to determine its effect on the system response, etc.
- **Part C** or the task section is the most interactive part. The user responds to questions that can take the form of MCQs, mini-games (for instance, rank items), or a simple calculation. The answer is then validated, hints can be provided in case of a mistake. An example is provided in Figure 2.

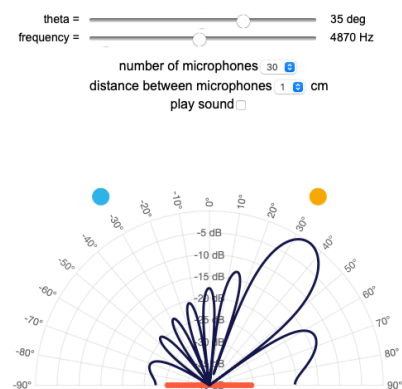


Figure 1: Java applet for computing a microphone array response. Beaming angle  $\theta$  can be moved to any direction. The frequency slider allows to get the directivity pattern for a particular frequency. Microphone number and spacing can also be changed. The effect of beamforming can be heard by clicking the "play sound" button which activates the two sources depicted by the colored circles.

On the web page, part A will always be visible, while parts B and C can be alternatively displayed via a switch button (see Figure 3).

## 3.2 Working tools and methods

When one wishes to carry out a collaborative work of this scale with partners from different countries, it is important to have appropriate digital tools. Here, the ASKnow consortium has benefited from the experience of previous courses (ACI and ACE) in order to propose templates and tools that are most likely to facilitate the

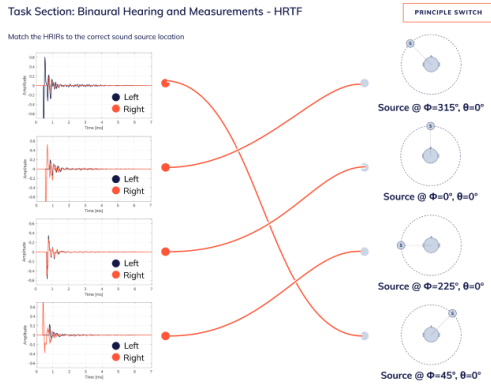


Figure 2: Example of a task for the course on psychoacoustics

transfer of the course resources to the final product (html format). For the theory part, it was decided to use the LaTeX format with the collaborative cloud-based LaTeX editor Overleaf. A .tex template has been designed and a routine has been developed by our partner Jazzy to automatically perform the latex to html conversion. For the principle and task parts, it was decided to use Figma, a web-based or desktop vector graphics editor and prototyping tool. To facilitate the work of course developers, templates were also provided. When the need arose, new templates were created to respond positively to requests. In order to keep a certain unity of design, a graphic charter (see Figure 4) has also been proposed.

To facilitate the communication between the project staff, Mattermost, a free instant messaging software, was used. General information (organization of meetings, dissemination actions, link with EACEA) but also exchanges on the content and form of the courses were regularly posted. A mail alias including all the people working on the project has also been created.

Finally, in order to monitor the progress of the project, online spreadsheets were used to track different actions: individual follow-up of each part (A, B, C) for each of the thirty lessons of the five courses, inventory of meetings, statistics, etc.

The conversion of the developed material is provided by our partner Jazzy innovations with KFB Acoustics. Figma and online spreadsheets are again used to discuss changes and monitor the progress of individual tasks. An example of a resource originally created by a partner and its modified version that fits the charter requirements is shown in Figure 5.

### 3.3 Pandemic situation

The covid-19 pandemic has had a significant influence on the smooth running of the project. It has prevented the in-person meetings that usually facilitate more in-depth discussions on the content of the courses than the online meetings do. It has also brought an extra workload to both academics and engineers to adapt to the new situation.

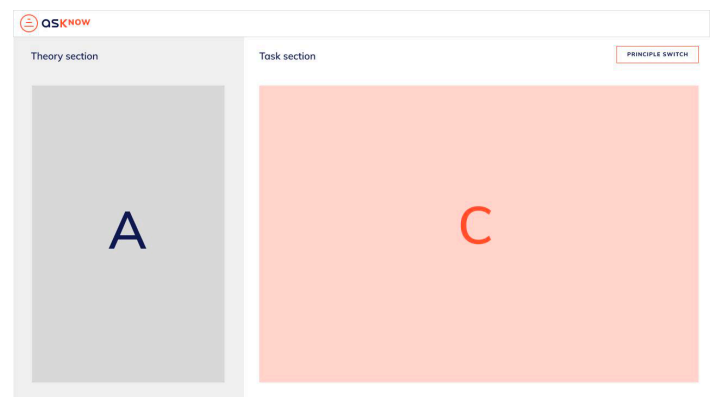
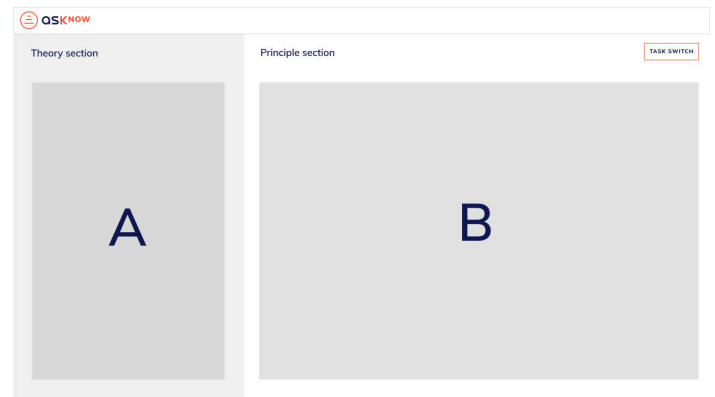


Figure 3: Template for the implementation of a lesson, part B (principle) can be switchable with part C (task).

Finally, some of the project staff have been directly affected by the disease, which caused interruptions in their work and delayed the overall progress of the project.

Fortunately, the use of online working tools allowed the work process to continue without sacrificing the quality of the developed resources. However, to absorb the difficulties caused by the pandemic, a six-month extension of the project was requested, and the request was granted by the EACEA.

## 4 Reviewing process

The reviewing process was carried out in several phases:

- The first phase was internal to the group that developed a particular course. All parts were reviewed, first each part individually and then one person reviewed the whole course.
- A second phase of review was carried out for each course by KFB, checking both for possible errors and the ease of porting the resources to an online platform.
- A final phase of external review is planned with specialists of the field outside the consortium, with for example researchers or professors from

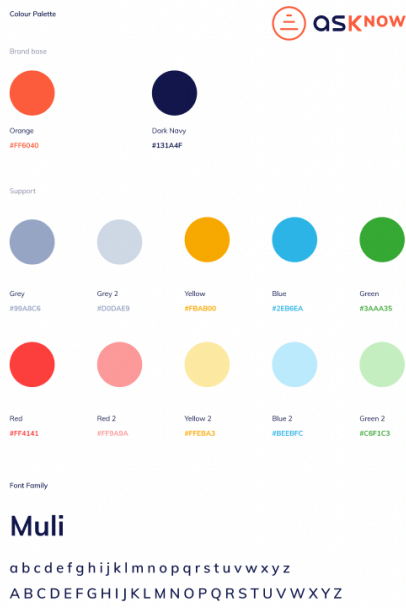


Figure 4: Excerpt of the ASKNow graphic charter.

the Universities of Valencia and Madrid (Spain), Chalmers University of Technology and the Joanna Jaboska Wroclaw University of Technology.

These steps are particularly important to ensure that the complexity level of the resources is appropriate, that the lessons can be easily understood, and that they are free of errors as much as possible.

As soon as the resources have been converted and adapted to their final online form, a test phase with the target groups (students and lifelong learners) will be implemented, with a dedicated survey tool to collect their feedback and comments. If necessary, the resources will be updated and corrected according to the received feedback.

## 5 Conclusion

Working on the creation of free online courses within the ASKNow project has been a very rewarding experience for all partners. As is often the case, the workload associated with the development of these materials was initially underestimated, and the unfortunate pandemic situation has emphasized this issue even more. Fortunately, the online working tools that have been set up, along with video conferencing and the means of instant messaging allowed the consortium to stay on track. The original resources have been finished within the allocated time that was extended by six months.

The course resources are currently being adapted to web format and should be available in the first semester of 2023. Dissemination actions will then be carried out to promote their use to colleagues in both the academic and industrial

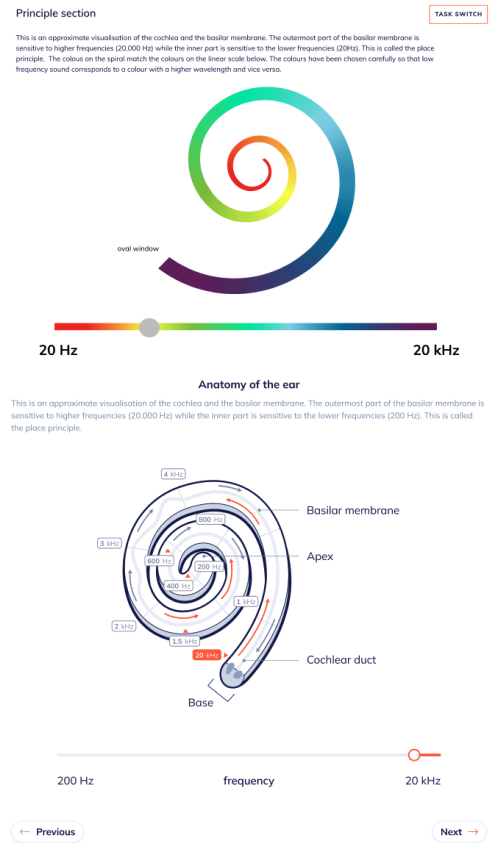


Figure 5: Example of a part B created by a partner (top), adapted version to fit the charter requirements (bottom).

domains. We look forward to sharing it with you to get your feedback and discuss potential collaborations.

## Acknowledgment

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