DOI: 10.61782/fa.2023.0864

forum acusticum 2023

OPEN-ACCESS INTERACTIVE ONLINE COURSEWARE IN ACOUSTICS DEVELOPED WITHIN THE SCOPE OF THE ACOUSTICS KNOWLEDGE ALLIANCE (ASKNOW) PROJECT

M. Horvat[1*] **S. Raetz**[2] **P. Lotton**[2]
Y. Sluyts[3] **M. Vorländer**[4] **A. Petošić**[1]
K. Jaruszewska[5] **A. Ray**[6] **B. Wojtyla**[7]
T. Wulfrank[8]

[1] University of Zagreb Faculty of EE and Computing, Unska 3, 10000 Zagreb, Croatia
[2] Laboratoire d'Acoustique de l'Université du Mans, UMR CNRS 6613, Avenue Olivier Messiaen, 72000 Le Mans, France
[3] KU Leuven, Department of Architecture, Campus Brussels and Ghent, Paleizenstraat 65/67, 1030 Brussels, Belgium
[4] Institute for Hearing Technology and Acoustics, RWTH Aachen, Kopernikusstraße 5, 52074 Aachen, Germany
[5] KFB Acoustics Sp. z o.o., Mydlana 7, 51502 Wroclaw, Poland
[6] HEAD acoustics GmbH, Ebertstraße 30a, 52134 Herzogenrath, Germany
[7] Jazzy Innovations Sp. z o.o., ul. Zygmunta Starego 22/42, 44100 Gliwice, Poland
[8] Kahle Acoustics, Avenue Molière 188, 1050 Bruxelles, Belgium

ABSTRACT

Several years ago, a consortium of several universities and companies was formed with the mission to disseminate the knowledge in the field of acoustics and make it more accessible to a wider circle of professionals, as well as to educators, students, specialists in other fields, and lay people. To make a constant and ongoing contribution to achieving this goal, the efforts of the consortium have since then been focused on developing interactive teaching materials disseminated through the freely accessible Acoustic Courseware (ACOUCOU) online platform. The consortium has undertaken several projects with the goal of developing specialized content for specific target audiences. Its most recent endeavour is the Acoustics Knowledge Alliance (ASKnow) project funded by the Erasmus+ Knowledge Alliances Programme of the EU. Its focus is put on developing teaching materials that cover five areas of acoustics: acoustic fundamentals, psychoacoustics, acoustic simulations and auralisation, electroacoustics, and room and building acoustics. As the project is now in its final stage, the intent of this paper is to present the results of the project by providing an overview of the content of the teaching materials that have been developed over the last three years in their final form and layout.

Keywords: *acoustics, online courseware, open-access, interactive.*

[*] ***Corresponding author***: marko.horvat@fer.hr

1. INTRODUCTION

The rate at which the technology changes in the modern world is ever-growing, thus encouraging, if not forcing the professionals and specialists to adopt new knowledge as fast and efficiently as they possibly can. While the educational institutions are focused on providing a solid basis on which future professionals can build their knowledge, they seem to struggle with the described

technological changes due to their infamous inertia exhibited in the process of adopting new curricula or changing the existing ones. Moreover, the development of problem-solving way of thinking is often underappreciated, if not completely overlooked.

The development of high-speed data communications in recent years, but also the occurrence of the COVID-19 pandemic has motivated the educators to resort to online learning by using a variety of audio-visual communication tools and online teaching materials available on different courseware platforms.

Due to the galloping changes many people cannot or do not want to cope with, the idea of pursuing a career in science, technology, engineering, and mathematics (STEM) does not seem to be particularly appealing to young people. Even though the development of technology in the field of acoustics is perhaps not as fast as it is in some other fields, the same phenomenon can be observed.

To answer to all these issues and try to bring the knowledge in the field of acoustics closer to professionals, students, educators, but also everyday users, the authors and their colleagues, with the cooperation of other partners, have decided to take on the challenge of creating a range of online teaching materials. These materials were, are and will be freely available to anyone who wishes to use them as a tool for improving their knowledge in acoustics. The result of this undertaking is the Acoustic Courseware (ACOUCOU) platform [1]. At this time, several projects have already been completed, and the resulting teaching materials that have been developed for specialized target groups are available on the platform. These are the Architectural Acoustics Multibook (ArAc Multibook), the Acoustic Course for Engineers (ACE) and the Acoustic Course for Industry (ACI). More information on the ACOUCOU platform and on these already existing materials can be found in [1-3].

The most recent endeavour is the Acoustics Knowledge Alliance (ASKNOW) project [4] undertaken by the consortium made up of four universities and four companies, aided by outside partners. The project is funded by the Erasmus+ Knowledge Alliances programme of the EU. The planned outcome of the project are the developed, freely available online teaching materials that cover five fields of acoustics: Acoustic fundamentals, Psychoacoustics, Acoustic simulations and auralisation, Electroacoustics, and Room and building acoustics.

The project and its outcomes have already been advertised through different channels, including previous publications [5-8], in which the project is presented in detail: its structure, objectives, work strategies, challenges encountered along the way, and samples of intermediate results, i.e. the developed materials in their raw form.

Therefore, the goal of this paper is to present the content of the teaching materials in as much detail as possible. Explanation will be given on how the teaching materials are structured. The list of lessons that cover each of the five topics will be given as well. As the project is nearing its completion, selected samples of the teaching materials in their final form will be shown for each of the five topics.

2. THE STRUCTURE OF THE TEACHING MATERIALS

The teaching materials are divided into lessons as elementary particles of knowledge. Each of the five topics has been covered with 30 lessons that form a corresponding course. Additionally, there are two practical cases per course that strive to illustrate the problems that are often encountered in a particular area of acoustics, and to offer solutions that are in line with the knowledge gained by the user while going through the lessons in a course.

The lessons are made of the theory part (part A), the principle part (part B), and the task part (part C). The theory part explains the phenomenon covered in the lesson using text aided with equations, figures, and tables. The principle part illustrates the underlying principle of the phenomenon by using audio-visual learning content such as charts, animations, interactive calculations, videos, sound samples one can listen to, etc. In the task part, the users need to solve one or more short tasks in form of questions with multiple-choice answers, calculation tasks, grouping of images or other objects into appropriate categories, etc.

The devised general layout of the lessons that has been implemented in the online materials is shown in Figure 1.

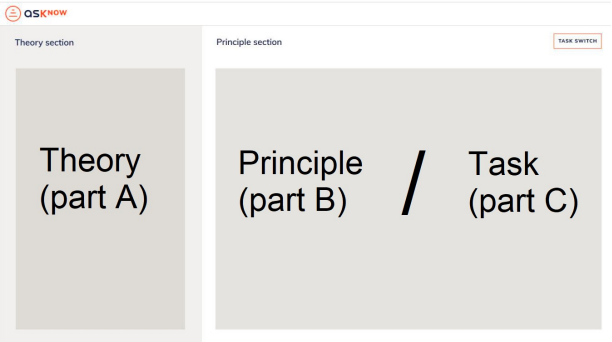

Figure 1. The devised layout of a lesson.

The layout of a lesson was designed as a split screen, in which the left part of the screen contains the theory part (part A), and the right part of the screen contains the principle part (part B). A switch has been provided that allows the user to change between the principle part and the task part (part C) in the right part of the screen. This layout has been adopted to allow the users to always have the theory part available on the left. This way, they can always access this information, regardless of what they are doing on the right side of the screen, i.e. using the principle part to gain a deeper understanding, or solving the task to check what they have learned.

3. ACOUSTICS FUNDAMENTALS

The course that covers this topic strives to explain the fundamental concepts in acoustics as the basis for understanding and solving problems in applied fields of acoustics.

The first section of this course deals with the basics on sound and waves / 1D acoustics (tubes) and contains the following lessons: 1 - Definition, what is a wave, speed of sound, physical quantities involved, order of magnitude; 2 - 1D equations of acoustics; 3 - Solutions of acoustic equations in the time domain; 4 - Equation of acoustics and their solutions in the frequency domain – stationary waves, SWR; 5 - Reflection; 6 - Transmission and reflection; 7 - Impedance; 8 - Proper frequencies and modes; 9 - Acoustic intensity and losses.

The second section presents 3D waves and sources through the following lessons: 10 - 3D equations of acoustics; 11 - Plane wave in 3D; 12 - Snell-Descartes laws; 13 - Spherical wave and pulsating sphere; 14 - Monopole, dipole, and quadrupoles; 15 - Solutions of wave equation in spherical coordinates; 16 - Radiation of a plane surface; 17 - Diffraction.

The third section focuses on waveguides and cavities and encompasses the following lessons: 18 - Boundary conditions and degrees of freedom; 19 – Waveguides; 20 - Modes in a cavity; 21 - Resonance in a cavity.

The final section focuses on miscellaneous topics required for a basic understanding of acoustics via the following lessons: 22 - The dB scale; 23 - Sources summation, 24 - Image sources, 25 - Dispersion, group and phase velocity; 26 – Dissipation; 27 - Surface impedance of materials; 28 - Transmission lines and analogies; 29 - Matricial formalism for waveguides; 30 - Horns.

4. PSYCHOACOUSTICS

The course that covers this topic deals with human perception of sound and the applications used in research and technology that stem from the underlying phenomena of sound perception.

The first section of this course deals with human perception of sound and consists of the following lessons: 1 - Anatomy of the ear; 2 - Signal processing of sound by humans; 3 - Bark bands (critical bands); 4 - Masking effects; 5 - Hearing threshold (How it is measured / age-related changes).

The second section introduces the psychoacoustic parameters in the following lessons: 6 - Introduction to psychoacoustics; 7 - Loudness; 8 - Roughness and fluctuation strength; 9 - Tonality; 10 - Sharpness.

The third section focuses on binaural hearing and measurements via the following lessons: 11 - Introduction to binaural hearing; 12 - Sound source localization; 13 - Head-related transfer function; 14 - Hearing models; 15 - Binaural recording and measurement; 16 - Equalization.

The fourth section explains the concept of speech intelligibility through the following lessons: 17 - Speech production; 18 - Lombard speech; 19 - Speech in reverberation and noise; 20 - Binaural unmasking; 21 - Assessment of speech intelligibility (C50, D50, U50, STI).

The fifth section describes psychoacoustic listening tests procedures covered with the following lessons: 22 - Introduction to listening experiments; 23 - Design of listening experiments; 24 - Common experimental methods (common listening test procedures); 25 - Statistical evaluation of listening experiments; 26 - Sound system quality evaluation testing.

The ultimate section introduces further perceptual matters in the following lessons: 27 - Perception of space, rooms, and distance; 28 - Introduction to the soundscape approach; 29 - Perceptual evaluation of noise; 30 - Auditory illusions.

The course culminates with two practical cases as examples of the use of adopted concepts in real-life applications. The first case focuses on the production of aurally correct recordings, so that they can be used in a listening test designed to yield a sound quality metric based on the established psychoacoustic parameters. The second one gives an example of a listening experiment focused on human ability to correctly localize sound sources.

5. ACOUSTIC SIMULATIONS AND AURALISATION

This course deals with the topic of acoustical simulations and the resulting auralisation as a type of signal processing that enables us to understand and perceive the meaning of

measured or simulated data by listening to sound samples that stem from that data.
The first section of this course is an introductory section composed of the following lessons: 1 - Introduction and overview of acoustical simulation; 2 - Impulse responses; 3 - Convolution; 4 - Fourier transform; 5 - Discrete processing.
The second section deals with the foundations of room acoustic simulations through the following lessons: 6 - Geometrical acoustics; 7 - Prediction of reverberation time; 8 - Image source model; 9 - Ray tracing; 10 - Radiosity methods; 11 - Wave-based models.
The third section establishes models for noise control and sound design via the following lessons: 12 - Environmental sound propagation; 13 - Airborne sound in buildings; 14 - Impact sound in buildings; 15 - Binaural transfer path analysis.
The fourth section focuses on auralisation and consists of the following lessons: 16 - Binaural synthesis; 17 - Synthesis of room impulse responses; 18 - FIR convolution; 19 - Real-time convolution.
The fifth section discusses the techniques of sound reproduction in the following lessons: 20 - Headphones; 21 - Binaural loudspeaker reproduction; 22 - Stereo and vector-base amplitude panning; 23 - Panning techniques and object-based audio; 24 - Ambisonics.
The last section presents the applications and evaluation of simulations through the following lessons: 25 - Architectural design; 26 - Noise mapping; 27 - Application of simulation and auralisation in research; 28 - Uncertainties of simulations; 29 - Interactive VR systems; 30 - Perceptual evaluation.
The two practical cases show 1) a common issue in architectural acoustics, i.e. the similarities and the differences between the acoustic simulation of a closed space and actual measurements, and 2) the application of binaural transfer path synthesis on a car simulator.

6. ELECTROACOUSTICS

As indicated by its very name, electroacoustics is a symbiosis of electrical engineering and acoustics, and it connects the electrical, mechanical, and acoustical domain.
The lessons developed in this course are divided into seven sections, the first one being about the background knowledge for electroacoustics (refreshers) and containing the following lessons: 1 - Introduction to electroacoustics; 2 - Basics of electricity; 3 - Mechanics: damped harmonic oscillator; 4 - Acoustical circuits; 5 - Mechanical-acoustical-electrical analogies; 6 - Radiation of simple acoustic sources.
The second section deals with the characterization of audio systems and consists of two lessons: 7 - Linear characteristics of transducers; 8 - Transducer limitations.
The third section explains the most common transduction processes through the following lessons: 9 - Electrodynamic transduction; 10 - Electrostatic transduction; 11 - Acoustical-mechanical transduction.
The fourth section focuses on modelling of transducers and illustrates it via the following lessons: 12 - Electromechanical source: the shaker; 13 - Electromechanical sensor: the geophone; 14 - Directive microphones; 15 - Electrodynamic microphone; 16 - Electrostatic microphone; 17 - Unidirectional electrodynamic microphone; 18 - Electrodynamic moving coil loudspeaker; 19 - Thiele & Small parameters: theory and measurement.
The fifth section explains the common loudspeaker systems in the following lessons: 20 - Closed box system; 21 - Vented box system; 22 - Other types of enclosures; 23 - Multichannel speaker systems.
The sixth section is oriented on advanced modelling of loudspeaker systems presented by three lessons: 24 - T&S model limits; 25 - Advanced parameters estimation; 26 - Loudspeaker nonlinearities.
The final section depicts the finer points of multi-transducer designs through the following lessons: 27 - Microphone arrays; 28 - Loudspeaker arrays; 29 - Personal sound zones; 30 - Playback systems.
The two practical cases illustrate the process of designing a two-way loudspeaker system and the measurements made on a loudspeaker driver.

7. ROOM AND BUILDING ACOUSTICS

This course strives to cover all three main components of the overall acoustic comfort assigned to rooms and/or buildings, i.e. the room acoustics, which tries to achieve appropriate acoustic conditions within a room, building acoustics, which deals with the protection of the room from sound coming from adjacent spaces and/or vice versa, and internal noise generated by noise sources in the room.
The lessons developed in this course are divided into two major sections preceded by an introductory lesson: 1 - What is the difference between room acoustics and building acoustics?
The section on room acoustics is composed of the following lessons: 2 - How a room responds to sound; 3 - Acoustic treatment - absorption, reflection, and diffusion; 4 - Volume

and shape of the room and their influence on room acoustics; 5 - Reverberation time; 6 - How a sound source interacts with a room; 7 - How loudspeakers interact with rooms; 8 - Acoustic elements - absorbers; 9 - Acoustic elements - diffusers; 10 - General requirements for good acoustics; 11 - Objective and subjective parameters in room acoustics; 12 - Room and building acoustics design criteria; 13 - Single-speaker and multi-speaker environments; 14 - Acoustics of spaces for music; 15 - Room acoustic design elements at the disposal of architectural design.

The section on building acoustics (and noise) consists of the following lessons: 16 - Airborne and impact sound, direct and flanking transmission; 17 - Sound reduction index for simple and composite structures; 18 - Single-leaf and double-leaf walls; 19 - Floors and ceilings; 20 - Facades: curtain walls; 21 - Doors and windows; 22 - Measurement and evaluation of airborne and impact sound insulation; 23 - Acoustic classification of sound insulation; 24 - Examples of good and bad constructions and workmanship practice; 25 - Influence of absorption on sound insulation (or how room acoustics influences building acoustics); 26 - Materials in practice; 27 - Towards more sustainable and low-energy produced materials for buildings; 28 - Special construction types using vibration isolation; 29 - Background noise and the sources contributing to it; 30 - Practical approaches for innovative, sustainable, and cost-effective buildings.

The two practical cases illustrate the implementation of the principles of room and building acoustics to real-life building designs.

8. EXAMPLES OF DEVELOPED MATERIALS

This section presents selected examples of the teaching materials in their final form, i.e. as images that depict their layout and static content. The full interactivity of the courseware material will be demonstrated once it has been uploaded to the ACOUCOU platform site. Since all the theory parts (part A) of the lessons follow the same structure, i.e. text with figures, tables and equations, the examples shown here have been chosen from the principle (part B) and task (part C) parts of selected lessons from all five courses, in which the authors of the lessons have truly displayed their inventiveness and creativity.

Figure 2 shows the principle part of the lesson on resonance in a cavity in the Acoustics fundamentals course. The user can choose the position of the source inside a shoebox-shaped cavity and the excitation frequency and observe which cavity resonances have (or have not) been excited.

Figure 3 shows the principle part of the introductory lesson on binaural hearing in the Psychoacoustics course that illustrates the advantage of binaural hearing for selective listening. The user can listen to a mono recording and a binaural recording and compare his/her ability to shift the attention between the two nearby speakers.

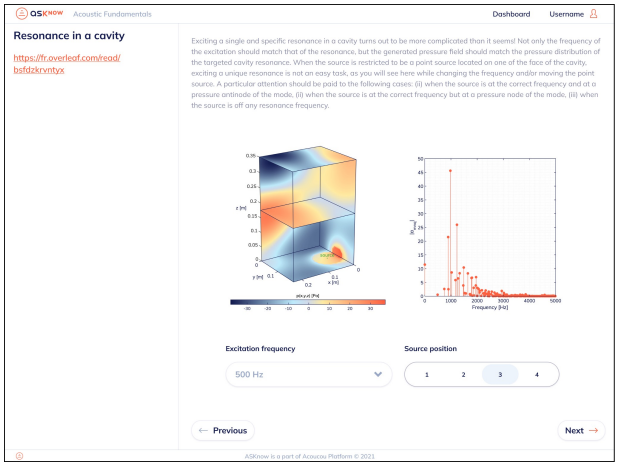

Figure 2. The principle part of the lesson on resonance in a cavity.

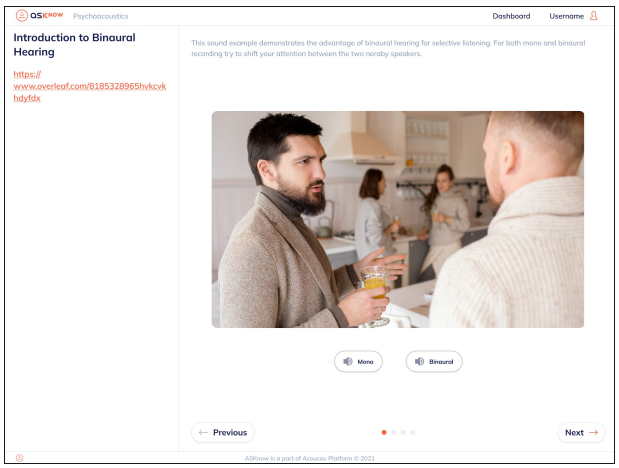

Figure 3. The principle part of the introductory lesson on binaural hearing

Figure 4 displays the principle part of the lesson on prediction of reverberation time in the Acoustic simulations and auralisation course. The user can select the dimensions of a shoebox-shaped room and assign materials and the corresponding frequency-dependent absorption coefficients to its surfaces. The application then calculates the equivalent absorption areas and the reverberation time

according to Sabine and Eyring, with or without air absorption.

Figure 5 displays the principle part of the lesson on electrostatic transduction in the Electroacoustics course. Audio signal is being fed to an electrostatic transducer that reproduces sound. The user can change the direct-current bias voltage across the transducer and listen to either a piece of music or a sine signal to discover how the change in bias voltage affects the reproduction of sound.

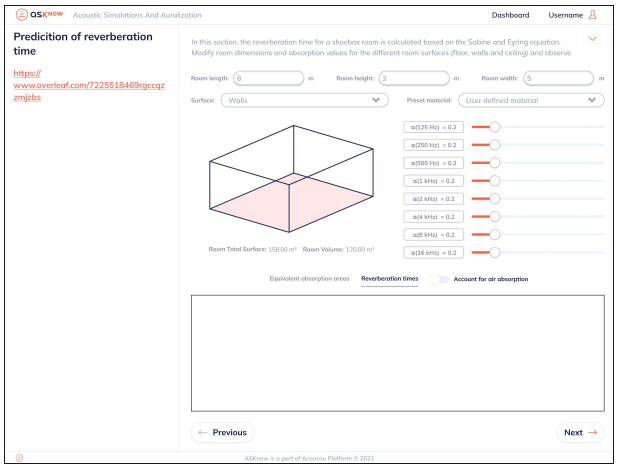

Figure 4. The principle part of the lesson on prediction of reverberation time.

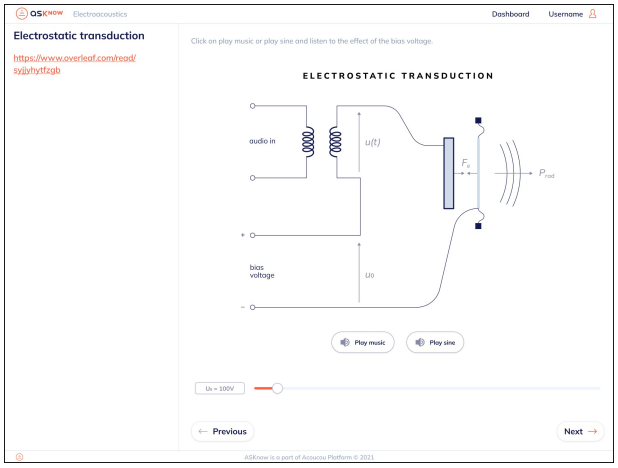

Figure 5. The principle part of the lesson on electrostatic transduction.

Figure 6 shows the principle part of the lesson on the interaction of loudspeakers and rooms in the Room and building acoustics course. It involves a model of a mid-sized sports hall equipped with a sound system. The user can change loudspeaker directivity (omnidirectional or directional), the number of loudspeakers (one above the listener or all ten), sound pressure level (normal or high) and the acoustics in the hall (treated or untreated). For each case, the user can listen to a sample or auralized speech to compare how the ratio of direct to reverberant sound and speech intelligibility changes in various conditions.

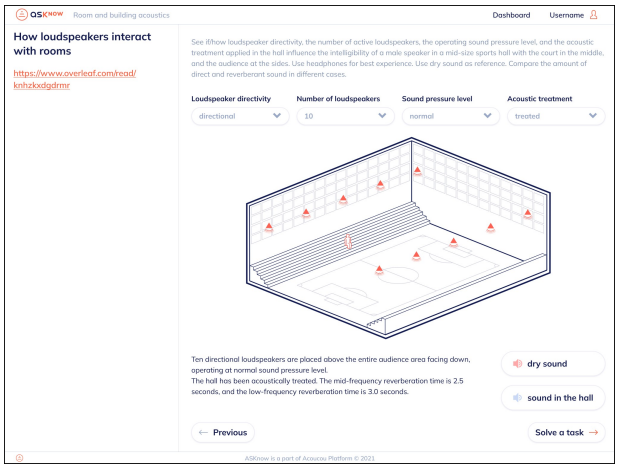

Figure 6. The principle part of the lesson on the interaction of loudspeakers and rooms.

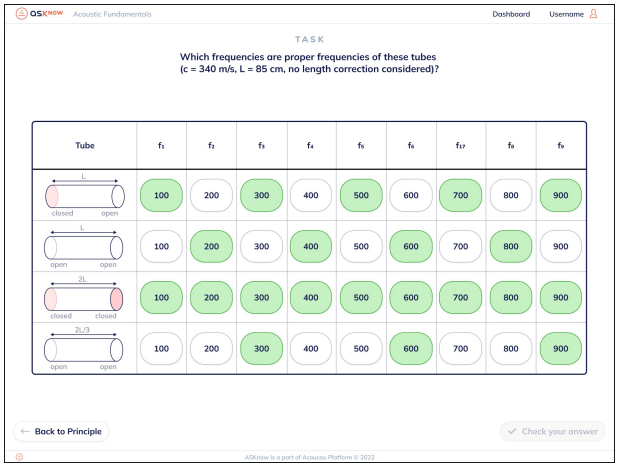

Figure 7. The task part of the lesson on proper frequencies and modes.

Figure 7 displays the task part of the lesson on proper frequencies and modes in the Acoustics fundamentals

course. The user is given four different tubes with different lengths and termination conditions (both ends open, both ends closed, one end open and the other one closed). The task is to calculate the proper frequencies of all four tubes and identify them by clicking on them.

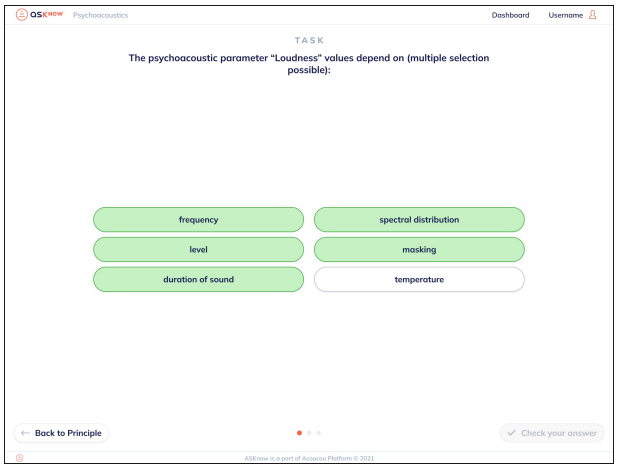

Figure 8. The task part of the lesson on loudness.

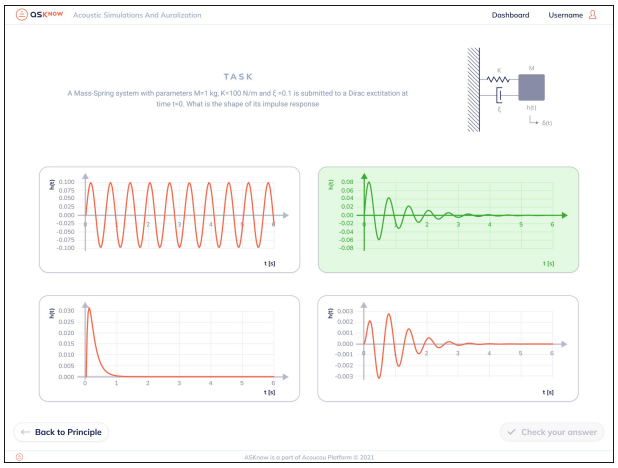

Figure 9. The task part of the lesson on impulse responses.

Figure 8 shows the task part of the lesson on loudness in the Psychoacoustics course. In this case, the users are asked to give their answer(s) to a multiple-choice question related to the factors that influence the final value of loudness.
Figure 9 displays the task part of the lesson on impulse responses in the Acoustic simulations and auralisation course. The key parameters of a mass-spring system are given to the users, and they are asked to select the correct response of that system to a Dirac excitation, i.e. the impulse response of the system.
Figure 10 shows the task part of the lesson on the electrodynamic moving coil loudspeaker in the Electroacoustics course. The user is given four impedance curves measured for a low-frequency driver, a full-range driver, a midrange driver, and a tweeter, and is asked to identify the appropriate impedance curve for each of the drivers.

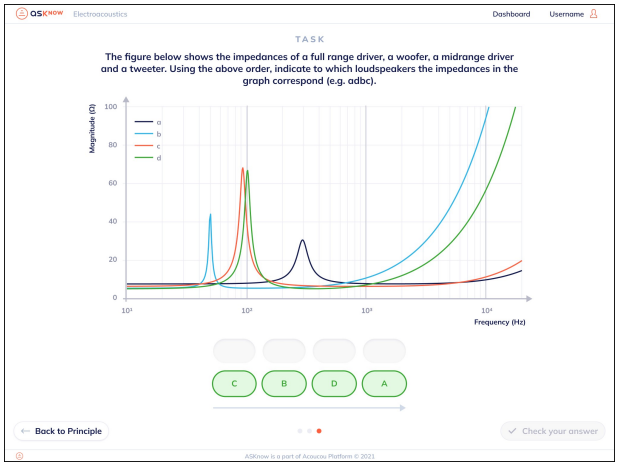

Figure 10. The task part of the lesson the electrodynamic moving coil loudspeaker.

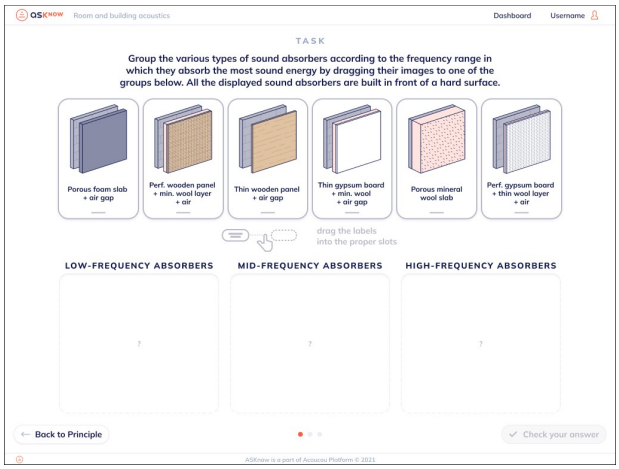

Figure 11. The task part of the lesson on absorbers as acoustic elements.

Finally, Figure 11 shows the task part of the lesson on absorbers as acoustic elements in the Room and building acoustics course. The user is given six different types of acoustic elements (or building constructions) that display sound absorbing properties and is asked to identify them as low-, mid- or high-frequency absorbers by dragging their images into the appropriate group.

9. CONCLUSIONS

In conclusion, the Acoustics Knowledge Alliance (ASKNOW) project has successfully developed a range of comprehensive and freely available online teaching materials covering various fields of acoustics. The project has been undertaken by a consortium of universities and companies, aided by outside partners, and funded by the Erasmus+ Knowledge Alliances programme of the EU. The ASKNOW course covers five main topics: acoustics fundamentals, psychoacoustics, electroacoustics, acoustic simulation, and building acoustics. The course materials are presented in an interactive way, making the learning experience engaging and effective for users. With the ASKNOW course, anyone interested in improving their knowledge in acoustics can access high-quality, comprehensive teaching materials for free.

10. ACKNOWLEDGEMENTS

All the activities within the Acoustics Knowledge Alliance (ASKNOW) project (project reference: 612425-EPP-1-2019-1-FR-EPPKA2-KA) have been funded by the Education, Audiovisual and Culture Executive Agency (EACEA) through the ERASMUS+: Knowledge Alliances programme.

11. REFERENCES

[1] https://acoucou.org, the homepage of the ACOUCOU platform, last accessed on 25 April 2023

[2] K. Jaruszewska, F. Barański, M. Piotrowska, M. Melon, O. Dazel, M. Vorländer, L. Aspöck, M. Horvat, K. Jambrošić, M. Rychtáriková, L. Kritly, A. Herweg, "ACOUCOU Platform to Acquire Professional Skills and Knowledge in the Field of Acoustics.", in *Proc. of the 23rd International Congress on Acoustics*, (Aachen, Germany), pp. 4348-4355, 2019.

[3] K. Jaruszewska, M. Melon, O. Dazel, M. Vorländer, L. Aspöck, T. Wulfrank, K. Jambrošić, M. Horvat, M. Rychtáriková, Y. Sluyts, B. Wojtyla, A. Herweg, F. Barański, "ACOUCOU - online platform including interactive educational materials about acoustics", in *Proc. of Forum Acusticum 2020*, (Lyon, France), pp. 3023-3024, 2020.

[4] https://asknow.acoucou.org, the homepage of the ASKNOW project, last accessed on 31 August 2021

[5] M. Horvat, M. Melon, K. Jaruszewska, T. Wulfrank, Y. Sluyts, A. Herweg, L. Aspöck, B. Wojtyla, "Acoustics Knowledge Alliance (ASKnow) project as the latest addition to the Acoustic Courseware (ACOUCOU) learning platform", in *Proc. of the 9th Congress of the Alps-Adria Acoustics Association*, (Budapest, Hungary), pp. 160-168, 2021.

[6] M. Horvat, K. Jaruszewska, S. Raetz, E. Carayol, Y. Sluyts, A. Herweg, L. Aspöck, S. Zeman, "The development of modern, interactive acoustic courseware material within the Acoustics Knowledge Alliance project", in *Proc. of the Euroregio – BNAM 2022 Joint Acoustics Conference*, (Aalborg, Denmark), pp. 225-234, 2022.

[7] M. Melon, Y. Sluyts, A. Heimes, M. Horvat, K. Jaruszewska, A. Herweg, , B. Wojtyła, J.-P. Dalmont, "Open access online course in acoustics in the frame of AcouStics Knowledge alliance (ASKnow) project", in *Proc. of the 16ème Congrès Français d'Acoustique*, (Marseille, France), pp. 1-6, 2022.

[8] K. Jaruszewska, M. Melon, O. Dazel, M. Vorländer, M. Rychtáriková, M. Horvat, T. Wulfrank, A. Herweg, L. Aspöck, Y. Sluyts, K. Jambrošić, E. Carayol, B. Wojtyla, M. Łuczak, V. Chmelík, "The ACOUCOU platform: Online acoustic education developed by an interdisciplinary team", *J. Acoust. Soc. Am.*, vol. 152, no. 3, pp. 1922-1931, 2022.