JASA ARTICLE

Developing experimental skills: A hands-on course in acoustical measurement techniques at the Norwegian University of Science and Technology[a]

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ABSTRACT:
The course "Acoustical Measurement Techniques TTT4250," offered by the Acoustics Group at the Department of Electronic Systems, Norwegian University of Science and Technology, is a fourth-year course in the specialization of acoustics in the five-year master program "Electronics Systems Design and Innovation" or MTELSYS, and the two-year international master program "Electronic Systems Design" or MSELSYS. It is one of the four required courses for MTELSYS and one of the two required courses for MSELSYS. It offers a hands-on approach to acoustics. This paper outlines the topics covered in this course and the involvement of several academic staff members, as well as invited industry and research institute guest speakers, as teachers. The assessment of laboratory reports is described, and general lecture topics, including measurement uncertainty and statistics, the introduction of standards, and programming, are also described. All aspects of the course aim to maximize students' experience with a broad range of acoustic measurements and their interest in acoustics.
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I. INTRODUCTION

At Norwegian universities, the teaching calendar is carried out over two semesters: the autumn semester, which typically runs from late August until late December, and the spring semester, which runs from the second week of January until late June. Each semester has a duration of 14 weeks of teaching followed by a four-week examination period. Most courses at the Norwegian University of Science and Technology (NTNU) have 7.5 course credits. The Master of Engineering degree is a five-year degree, in which students typically take four courses per semester in the first four years, resulting in 60 course credits per year. Students take two courses plus a project with 15 credits in the fifth year, corresponding to two courses in the first semester. The students finally write a master's thesis in the second semester with 30 course credits. Many five-year master's programs in engineering have three years of fixed courses for all students and different specializations for the last two years. In addition, NTNU offers many two-year master's programs in engineering, and they often have the same specializations as the five-year master's programs.

The five-year MSc program, "Electronics Systems Design and Innovation" (MTELSYS), and the two-year MSc program, "Electronic Systems Design" (MSELSYS), have five different specializations and acoustics[1] is one of those. The course structure of the acoustics specialization is illustrated in Table I. It shows how the acoustics courses are distributed over the two years.

Some universities have a similar program structure with a specialization in acoustics in programs in electrical engineering, physics, building engineering, or mechanical engineering. Other universities might have dedicated two-year master's programs in acoustics, some examples of which are Refs. 2–5.

At NTNU, a course in the acoustics specialization entitled, "TTT4250 *Acoustical Measurement Techniques*," is offered in the second semester of the fourth year in MTELSYS and the second semester of the first year in MSELSYS. This course gives 7.5 course credits and is only offered during the spring semester each year. The average number of students in this course has been 13 since it began in 2012, including students from MTELSYS and MSELSYS. In addition, a few students from other five-year master's programs at the faculty of Civil Engineering at NTNU and some foreign exchange students select this course. The class meets every week for a two-hour lecture offered by several teaching staff from the Acoustics Group in the Department of Electronic Systems (IES) at NTNU. In addition, laboratory sessions are held by a course assistant; generally, a Ph.D. student is identified before the commencement of the semester to assist with measurement tasks and the marking of the initial assessment and final evaluation.

This course was heavily inspired by a similar course in the international master's program, "Sound and Vibration" at Chalmers University, Gothenburg, Sweden.[2]

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TABLE I. The course structure of the acoustics specialization. F, fieldwork; L, laboratory work or measurements.

First year		Second year	
Fall	Spring	Fall	Spring
Music acoustics and technology (L)		Specialization course (F)[a]	Master thesis[a]
Marine acoustics (F)	Audio technology (L)	Student project[a]	
Technical acoustics (F)[a]	Acoustical measurement techniques (L)[a]		

[a]A compulsory course.

The course aims to provide experience with acoustic measurement techniques and instrumentation. Students can collaborate around the solution of practical measurement tasks and evaluate the quality of the measurement results. To achieve these aims, a wide range of measurement tasks, lecture material, and preparatory exercises was carefully selected. Also, industrial acoustic consultants and researchers from research institutions and industries provide stimulating guest lectures.

It can be noted that several other courses on acoustics also include laboratory work or fieldwork; see Table I. Thus, it is not the purpose of the Acoustical Measurement Techniques course to gather all of the laboratory work of the acoustics specialization. Practical skills are only developed through continuous practice.

This paper reviews the course, TTT4250 Acoustical Measurement Techniques, at NTNU. It is organized as follows. Section II outlines the course, including the content, learning outcome, and learning method and activities. Section III presents laboratory measurement tasks, including introductory lectures, preparatory exercises, and guest lectures. Section IV includes general aspects, including measurement uncertainty and statistics, the introduction of standards, and programming. The laboratory facilities used for this course are described in Sec. V. Assessment and evaluation criteria for the course are presented in Sec. VI. Student feedback and the resulting changes to the course over the years are described in Sec. VII. Section VIII presents a summary.

II. COURSE DESCRIPTION

This section describes the course by content, learning outcome, learning methods and activities, course material, and the collaboration with a research institution.

A. Course content

The course contains a part on the fundamentals of transducers and the signal processing and statistics involved in an acoustic measurement. The rest of the course covers a wide range of typical measurement tasks in acoustics, ranging from sound radiation to room and building acoustics, marine acoustics, psychoacoustics, and hearing.

B. Learning outcomes

The course provides experience with acoustic measurement techniques and instrumentation. Through the course, students develop a good knowledge of the theory behind common measurement tasks in acoustics. They acquire a deep understanding of accuracy with regard to transducers and acoustic instruments, environmental conditions, and the signal processing involved in an acoustic measurement situation. The students are also exposed to national and international standards for acoustic measurements. They master skills to perform standardized measurements according to relevant standards, analyze stochastic and systematic errors that affect acoustic measurements, and write informed and accurate reports on the setup and execution of standardized measurements. In general, students can collaborate around the solution of practical measurement tasks and evaluate the quality of the measurement results.

C. Learning methods and activities

The course contains lectures and a list of laboratory exercises (LEs) that cover a wide range of measurement tasks in acoustics. There are lectures on the specific theory behind the measurement technique at hand for each LE. Furthermore, there are preparatory exercises that students must do before the actual LE is performed. Preparatory exercises and a written laboratory report must be handed in independently by each student, and this material will be the basis for the final grade in the course. There is no final exam, and the final grade is the sum of the grades for each laboratory report. LEs largely follow international standards for the relevant measurement. Two or three students in one group carry out measurement tasks, and most of the measurements are performed in a large hall in the same building as the acoustics group is located.

D. Course material

The course material consists of lecture notes and slides developed specifically for this course, as well as a collection of papers and books[6,7] relevant to the LEs. A compendium describes the LEs, preparatory exercises for each LE, requirements for presenting the LE results, and guidelines for report writing.

E. Collaboration with a research institution

One of the LEs offered in this course is also in direct collaboration with SINTEF,[8] one of Europe's largest independent research organizations, working closely with NTNU and located on the campus. The LE uses the facilities of SINTEF, although the experiment could be performed at NTNU's facilities as well. The use of SINTEF's facilities allows the students to realize the collaboration between the Acoustics Groups at NTNU and SINTEF and get to know the research organization's location and working life, where some interested students may end up at some point in their careers. The LE presents a method to measure a person's hearing threshold, and was developed at SINTEF and NTNU in 2014, serving as an example of the topics and interests of this organization.

III. LABORATORY EXERCISES AND LECTURES

The course consists of five LEs, spanning a wide range of possible measurement tasks that can be encountered in acoustics. Some of the measurements are specified in national and international standards. The course was offered for the first time in 2012 when it consisted of six LEs. It was adjusted to five exercises in 2017. The LEs of the course as of 2021 consist of

- LE 1, sound power measurement;
- LE 2, measurement of sound insulation;
- LE 3, acoustic impedance measurement;
- LE 4, directivity of an underwater transducer; and
- LE 5, hearing.

Each LE is introduced by a lecture that gives the necessary theory, measurement guide and instructions, and relevant ISO standards for some of the measurement tasks. Each lecture is given one week before the actual measurements are performed.

Although the LEs can be scheduled in a varying order from one year to the next, the introduction to the corresponding lecture takes the effort to show the connection between the different LEs in the sense that they give an overview of typical measures along an acoustic transmission channel from a source to a receiver in a real-world situation. On the source side, two important characteristics are sound power and directivity. The propagation part is investigated via acoustic impedance measurements. The receiver side is addressed by one LE on hearing properties.

A. Preparatory questions for the laboratory exercises

For each LE, the students get a list of 4–6 questions that they need to hand in before attending the exercise. The course assistant will grade these questions and give the students individual feedback. The preparatory questions were introduced some years after the course started in 2012 and were designed to address three aspects. The first is to ensure that the students have the necessary knowledge to understand the LE curriculum. Second, the students need to understand what is expected in a LE. Third, the students need to be sufficiently prepared for the LEs. Some questions are on concepts that students previously misunderstood, e.g., different mathematical and physical theories and parts of the LE methods and their constraints. These preparatory questions help the students perform better on laboratory tasks and report writing, as well as fill in knowledge gaps shown by previous students. Before each LE, the students can ask the course assistant to clarify the questions. They are also provided with a proposed solution to the questions, in which they can compare their answers before post-processing the different LE results.

B. Description of the laboratory exercises

A brief description of each LE is given in Secs. III B 1–III B 5.

1. LE 1: Sound power measurement

This LE is built around an unknown noise source, the sound power of which is to be determined from sound pressure level measurements or sound intensity measurements, assuming an *in situ* environment. Three standards are followed: ISO 3746,[9] ISO 3747,[10] and ISO 9614-2.[11] ISO 3746 relies on sound pressure measurements and assumes a free field above a reflective surface. ISO 3747 is also pressure based but applies to reverberant environments. ISO 9614-2 derives sound power from scans made with a sound intensity probe. The use of ISO 3747 allows determining the grade of accuracy achieved in a given measurement environment. Using several methods to determine the same quantity helps fuel the discussion of results in the LE report.

The practical aspects of the measurement of sound intensity deserve special attention. The reason is that the interpretation of the different F_i indicators, the concepts of *dynamic capability index*, and the *pressure-residual intensity index* considered by ISO 9614-2 are not immediate to everyone and provide insight into how sound intensity probes operate. The LE and lecture focus on general-purpose standards but standards and test codes that are dedicated to a particular source, such as IEC 61400:11 (Ref. 12) for wind turbines, are touched on.

2. LE 2: Measurement of sound insulation

This LE is built around a $1.46\,\text{m}^2$ wall element at the interface between two reverberation rooms. This element consists of a two-layered structure made of plywood and rubber. The students are requested to determine the sound reduction index, R, of this wall element from sound pressure level measurements and sound intensity measurements before computing the corresponding single number rating according to ISO 717-1.[13] They are then asked to compare the results from the two methods and also compare them with the theory of a single-wall partition. They are confronted with the signal-to-noise ratio issue in the receiving room because the sound power of the sound source is not sufficient at all frequencies. The major ISO standards for use in the laboratory and *in situ* are introduced in the lecture for pressure-based, intensity-based, and impulse-response-based measurements [ISO 18233 (Ref. 14)].

3. LE 3: Acoustic impedance measurement

In this LE, the absorption factor of a sample of fibrous panel is measured in the standing wave tube according to ISO 10534-2 (Ref. 15) and in a free field with a two-microphone spherical decoupling approach,[16] as shown in Fig. 1. The measurement results are compared with each other and with a simple one-parameter impedance model.[17] In both of the methods, the raw measurements are impulse

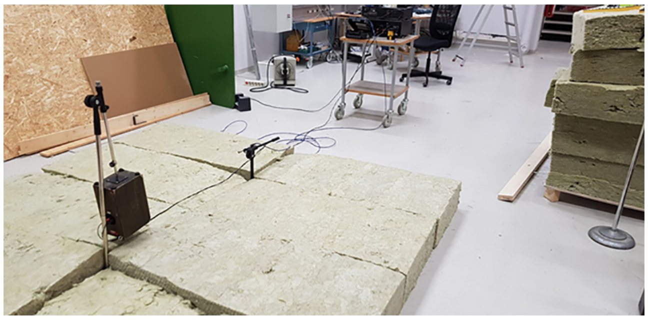

FIG. 1. (Color online) The setup is depicted for the spherical decoupling method used in laboratory exercise 3 to estimate the impedance of a sample of mineral wool from impulse-response measurements in two microphone positions successively.

responses obtained from swept sines. The development of the post-processing for the free-field measurement is arguably the most challenging programming task throughout the different LEs because the students must start from measured impulse responses.

The preceding lecture presents different ways to correct phase mismatches between the two measurement channels, i.e., using a reference sample or switching the microphones. Also, the primary standards for measuring absorption from flat boundaries are briefly reviewed.

4. LE 4: Directivity of an underwater transducer

The objectives of this LE are to get familiar with underwater acoustic instruments and practical aspects of underwater sound generation and sharpen the understanding of transducer characteristics. In this LE, the students measure the frequency response at three particular angles and the beam pattern and directivity at three distinct frequencies of an acoustic transmitting transducer in a water tank. The instruments used for the measurement include a transducer with a usable frequency range of 8–16 kHz, an omnidirectional and broadband hydrophone, a waveform generator, and an oscilloscope. First, the students generate a sinusoidal waveform with the frequency changed in steps and measure the frequency response of the transducer within the usable range at three different angles by rotating the transducers. Then, they measure the beam pattern or directivity of the transducer at different frequencies. The resulting frequency responses and beam patterns are plotted for comparison.

The preparatory exercises include calculating a source-receiver distance, which gives a far-field measurement for the usable frequency range, calculating the direct and reflected wave amplitudes, and plotting the beam pattern in polar coordinates given a measurement.

5. LE 5: Hearing

The hearing LE was developed with the overall goal of letting the students get some experience with hearing measurements on human subjects. More specifically, the students use the standard measurement procedure for measuring the hearing threshold with so-called pure tone audiometry (PTA) and get familiar with an automated method called New Early Warning Test (NEWT), which was developed and patented by SINTEF and NTNU in 2014.[6]

The LE consists of first measuring the hearing threshold of at least two subjects with both methods. Then, the NEWT method is used to measure the hearing threshold of a person wearing an over-the-ear hearing protector and another person wearing a foam earplug. The students are next asked to quantify the attenuation by the two different hearing protection devices. Finally, the students perform an uncertainty analysis on the results obtained by all of the course participants, where they compute the expanded uncertainty of the attenuation values, using the methodology in the ISO/IEC Guide 98–3, “Guide to the expression of uncertainty in measurement” (GUM).[18]

C. Additional lectures

In addition to the introductory lectures corresponding to the LEs, lectures on transducers, programming for measurement post-processing, measurement uncertainty, and statistics and standards are also given. Also, an introduction is given to EASERA,[19] a software for acoustic measurements. Most of the staff, including four academic staff and one senior engineer in the acoustics group, participate in lecturing. Industrial acoustic consultants and researchers from research institutions and companies are also invited to give guest lectures on various topics. These topics might be indoor and outdoor acoustic measurements, acoustic measurements related to human comfort onboard vessels and offshore installations, external underwater and airborne noise, nondestructive testing (NDT) with ultrasound, atmospheric infrasound, quality control in speaker production, and characterization of loudspeakers. There are typically two such guest lectures every year.

IV. GENERAL ASPECTS

A. Measurement uncertainty and statistics

One lecture presents how measurement uncertainty can be handled according to the ISO/IEC Guide 98–3, “Guide to expression of uncertainty in measurement.”[18] This approach has been gradually introduced into updated versions of various ISO measurement standards. In this course, the students are expected to use the approach only for the LE on hearing, where they must perform a few repetitions of the measurements to estimate the uncertainty from real data sets.

B. Standards

Due to its applied and experimental nature, the course offers an excellent opportunity to introduce the students to standards and standardization in acoustics. The distinction between precision-, engineering-, and survey-grade standards is presented with a discussion of the necessity of trade-offs. A balance must be found between minimizing measurement uncertainty and keeping manageable the requirements on the measurement environment, the measurement equipment (number of measurement channels and measurement class required), and the skills and human time needed. Concerning these trade-offs, the course clarifies the divide between laboratory standards and *in situ* standards. From an international perspective, the occasional distinction between regulations (limit values) and standards is presented. The most important standardization bodies from a European point of view and the hierarchical structure of committees and working groups are also outlined. Moreover, each laboratory that relies on standards instead of *ad hoc* measurement protocols is used as an opportunity to give an overview of the relevant standards. Such an overview can be valuable because the path from specific measurement needs to the identification of the relevant standard (provided that it exists) is not always obvious. This portion on standards benefits from the involvement of two teaching team members in standardization at the national and international levels.

C. Programming

Although the measurements are performed with dedicated hardware that does not require the students to write any code, the post-processing is left to the students. Arguably, this post-processing is not so easily done with spreadsheet software; therefore, a certain amount of computer programming is required. The students who take this course have various backgrounds and the task of writing a few tens of lines of code to analyze measurement data and plot relevant results proves challenging for many.

As part of the course, a refresher on programming and programming practices was introduced in 2021. It is, of course, beyond the scope of our course to teach programming. Among the major programming paradigms, the imperative one is followed. Based on typical suboptimal practices from the past years, the students are proposed several code snippets and screenshots. These examples are used to reflect on how to organize a computer folder in the context of laboratory work. For instance, separating data from processing, distinguishing libraries and scripts is proposed as good practice. Moreover, based on these code snippets, the relevance of comments, explicit variable names, arrays, loops, and functions is highlighted to improve code readability, reliability, and maintainability.

Whereas the discussion of this is programming-language-agnostic, examples in MATLAB or PYTHON are provided to make things more concrete, considering that these are the most popular programming languages among the students at the time of writing. Basic functions for interaction with the operating systems and string manipulations are also introduced as post-processing is also about manipulating files and folders. To minimize the programming effort, students are also provided with a short list of the MATLAB or PYTHON functions that are most relevant when it comes to writing post-processing scripts for the course, based on past laboratory reports.

This refresher closes on a task in which the students are asked a few questions about how to program the game of life[20] *before* implementing it in the programming language of their choice. Here, a non-acoustical problem is preferred to avoid any physics-related difficulty. Two sample questions are: What data structure would you use to represent the grid? and What would be the names of three relevant user-defined functions?

V. LABORATORY FACILITIES

The laboratories used in the acoustics measurements course are briefly described below.

A. Reverberation chamber

The reverberation chamber is built as a separate concrete structure, resting on a thick layer of absorbing foam to prevent interference from the outside. The structure has the dimensions 5.2 m × 8.5 m × 6.1 m, which gives a volume of 269.6 m^3. The chamber satisfies the requirements outlined in ISO 354 (Ref. 21) for sound absorption measurements.

Sixteen curved diffusers made from acrylic material and with various radii are hung from the ceiling. One of the walls has two openings leading into an adjacent smaller chamber (4.1 m × 5.6 m × 4.6 m) used as a source room in sound transmission measurements. The two openings are used for windows and doors. The reverberation chambers are shown in Fig. 2.

B. Underwater acoustics tank

The tank is made from steel-reinforced fiberglass and measures 3 m × 2.5 m × 2 m. The tank is equipped with two trolleys that slide on the top of the tank, which facilitate easy mounting and positioning of the equipment, as shown in Fig. 3.

C. Audiometry laboratory

The audiometry laboratory exercise is performed in two separate rooms, one for the traditional audiometry and one for the NEWT method. Figure 4 shows a photograph of the room for the NEWT method. The room dimensions are 6.5 m × 2.9 m × 2.4 m for the audiometry room and 4.1 m × 2.9 m × 2.4 m for the NEWT room.

VI. ASSESSMENT AND EVALUATION

The grade is based on the evaluation of the reports. If not passed, the course must be repeated in the next semester that it is offered. Each LE counts as 20% of the final grade. To improve the report writing, the report for the first LE is permitted to be submitted twice. The students get detailed feedback on the first report and can improve the report for the second submission. This is done to show the students the expected level of the reports and help them to better understand what should be included. Both attempts will contribute to the final grade, and each attempt gets 10% of the grade.

FIG. 2. (Color online) The two reverberation chambers used in the course are depicted. (a) The main room is used for the sound power and sound insulation laboratory exercise. (b) The adjacent smaller room is used as a source room for the sound insulation laboratory exercise.

The initial grading is completed by the course assistant and proofed by the responsible lecturers.

Students generally improve their report writing skills throughout the course, where the biggest improvement is seen from the first to second version of the first LE. For LEs 2–5, the students do not get detailed feedback but received general comments on each report section, making it possible to point out mistakes during the laboratory work, the post-processing, or repeated report writing errors. The students seem to appreciate this kind of constructive feedback, and they usually consider the comments to improve their reports. On average, the students better their report grades with 15.2 points (out of 100) from their first report to their final grade. Table II shows the average grades from the last four times the course was given (2018–2021).

FIG. 3. (Color online) The underwater acoustic tank and the setup for laboratory exercise 4, where a transducer for transmitting sound burst at different frequencies and angles is placed on a trolley to adjust the position and a hydrophone is deployed in the same plane to record the transmitted sound.

FIG. 4. (Color online) The room where the NEWT experiment is performed. The loudspeakers used for the NEWT are located on the walls to the left and right as shown in the picture. This room is usually also used to carry out standard audiometry tests.

A. Assessment criteria

Each report is assessed using predefined scores, which sum up to 100 credits. These scores reflect which part of the report "dominates." For example, the sound power LE will contain more theory than the hearing LE, and the percentage of credits going to the theory part is consequently higher. On the other hand, there is a stronger emphasis on the method section for the hearing LE, describing how the laboratory work was performed.

The 100 points are divided into different subgroups that assess how well the student performed in the different aspects of the report. We usually score content in preparatory exercises, introduction, theory, method, result/discussion, and summary/conclusion. In addition to these, we look at how well-written and structured the report is, that the referencing is consistent and correct, and the figures/tables are of sufficient quality. In other words, we are preparing the students for their master's thesis. From each subgroup, we give individual scores, which finally sum up to 100 points, which will be the basis of the report grade.

TABLE II. The average grades for each laboratory exercise.

Sound power version 1	Sound power version 2	Sound insulation	Acoustic impedance	Underwater transducer	Hearing	Final grade
63.8	79.6	81.5	77.2	80.6	81.4	79.0

B. Assisting students' work

The course assistant is present during the laboratory sessions. Usually, the laboratory session starts with the assistant explaining the basic concept of the laboratory work, different safety measures, and how different tasks should be performed. During the LE, the students can ask the assistant questions regarding the laboratory work, and as a general rule, the assistant will not give the students direct answers but instead guide them to find the answers themselves. When concluding the laboratory work, the students will save the data they have produced and start the post-processing.

There is no fixed time slot set for the course assistant to meet the students and assist with the preparatory questions or post-processing of the results. However, the students can send the assistant emails any time they prefer and receive feedback on their process and the different results. Furthermore, if there are repeating questions from the students, the answers to these are published in a shared forum (normally Blackboard, an e-learning system used by NTNU) so that all can benefit from them. If the assistant cannot answer the questions, the assistant forwards the questions to the professor responsible for the LE and gives them the possibility to provide an answer. Previous experience has shown that the course assistant should preferably answer the students as quickly as possible, making it easier for students to send further emails. This creates a good relationship between the students and the assistant. A quick response to emails is also essential as in-person help sessions are not offered.

VII. CHALLENGES AND COURSE IMPROVEMENT

Students in this course are from different study programs and come from diverse backgrounds, including exchange students from abroad. Some of them have a limited knowledge of acoustics, and their study programs might be electrical engineering, physics, civil engineering, mechanical engineering, music technology, etc. Some students have more experience with measurements and report writing, and others have little such experience. Some are afraid of operating measurement instruments. All of the aspects mentioned bring challenges for the teaching staff and course assistant.

There is a reference group consisting of at least three students in each course at NTNU. The reference group members are selected by volunteers while trying to get representatives from different backgrounds. Three meetings are held during the semester to gather students' comments on course content, lecture quality, problems met during measurements, and solicit suggestions. Actions based on the students' feedback through the reference group meetings and the report are taken during the semester and/or before the next course. As examples of the actions taken, obligatory preparatory exercises were introduced, and the number of LEs was reduced from six to five. Furthermore, individual assistance has been introduced for the students who do not have enough relevant background, all instruction texts were collected into a single booklet for the course, and the students were given clear rules for report content and size, which made grading more transparent. Finally, an extra lecture on programming was introduced.

In the event of a crisis like the COVID-19 pandemic, access to campus and laboratory facilities can be restricted, and an option is to replace indoor LE with outdoor LE. For the sound power measurements, it would be possible to propose an outdoor version of LE 1 with little effort. The same applies to LE 3, where ground impedance can be measured *in situ* instead of the impedance of building materials in the laboratory. With more effort, the measurement of sound insulation from a noise barrier can serve as a substitute for the current LE 2. An alternative to LE 4 on the pier of the Trondheim fjord without a boat is also possible. Concerning the hearing LE 5, there was no possibility to test the NEWT method. Still, instead, a test of the stapedius reflex was suggested and performed in one of the laboratory facilities of the acoustics group, which was accessible for small groups. All or part of the possible alternatives to the different LEs that are suggested here can become the default at universities where extended laboratory facilities are not available.

During COVID-19, there were occasions when students could not perform the laboratory work in person. The first time was when Norway's lockdown was introduced on 2020–03-12, and the students were not able to carry out the last LE in the course. Another case was in 2021 when one exchange student from France could not enter Norway in time for the course due to the national regulations at the time. In these cases, a sample dataset was collected by the course assistant and provided to those students together with a document explaining how the measurement was made. The student had to perform the laboratory work later and hand in a revised section on methods and results to show that they managed the LE.

For LEs requiring a well-controlled measurement environment, reusing existing measurement data and asking the students to focus on post-processing seems to be an acceptable workaround, although it is not entirely satisfying. This possibility was used in 2020 for the last LEs because the NTNU campus was closed to students.

VIII. SUMMARY

The course "Acoustical Measurement Techniques" at NTNU aims to provide experience with acoustical measurement techniques and instrumentation through a broad range of measurements, lectures, and preparatory questions corresponding to the laboratory exercises, guest lectures from research institutions and industries, and assessment of the reports. The lectures provide theory, standards, and procedures of the laboratory tasks. Preparatory exercises let the students investigate each LE and understand procedures for doing the laboratory work and processing the measured data. The guest speakers expose students to examples of real-world measurements encountered by acoustic consultants and other industry representatives. The course evaluations made by the reference group of the course during the years showed that students were satisfied with the course, and they were very receptive to the approach of the course, the LEs, preparatory exercises, assessment of their reports, and final grading scheme. The course is unique because it consists of a broad range of acoustic measurements and involves almost all of the staff in the acoustics group with a variety of expertise, which is rare at other universities.

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