Lessons Learned 1, 1&2 (2021)
Submitted: 28.05.2021
Accepted: 17.06.2021
DOI: https://doi.org/10.25369/ll.v1i1/2.16
ISSN: 2749-1293 (Print); 2749-1307 (Online)

Experimental case for experimental practicals@home

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Abstract

Experimentalpraktika sind ein wesentlicher Baustein im Studium der Ingenieurwissenschaft. Auch wenn virtuelles Lernen (u.a. Virtual-Reality-Experimente) eine gute Unterstützung für die Studierenden darstellt, spielen reell durchgeführte Experimentalpraktika insbesondere im ingenieurwissenschaftlichen Studium eine unverzichtbare, wichtige Rolle. Die experimentellen Versuche verbinden die Theorie und Praxis und motivieren die Lernenden zum Problemlösen.

Dieser Beitrag beschreibt am Beispiel des Projektes „Ingenieurkoffer für Experimentalpraktika@home“, wie Studierende trotz der besonderen Situation infolge der Coronavirus-Pandemie experimentelle Versuche auf dem Fachgebiet Dynamik eigenverantwortlich durchführen können, sowie die ersten Erfahrungen. Die Vor- und Nachteile der Nutzung des mobilen Ingenieurkoffers werden diskutiert und Ansätze zum effektiven Nutzen vorgestellt.

Experimental practical courses or practicals are an essential building block in the study of engineering. Even though virtual learning (including virtual reality experiments) has benefits for students, real experiments play an indispensable and important role, especially in engineering studies. The experimental trials connect theory and practice, and motivate learners to solve problems.

Using the example of the project "Ingenieurkoffer für Experimentalpraktika@home" (engineering case for experimental practicals@home), this paper describes how students can conduct experimental trials in the field of dynamics on their own, despite the special circumstances resulting from the coronavirus pandemic, as well as the initial experiences. The advantages and disadvantages of using the mobile engineering suitcase are discussed and approaches on how to effectively use them are presented.

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This article was originally submitted in German.

1. Introduction

Experimental practical courses are an essential building block in the study of engineering. Their importance is reflected for example in the following aspects: linking theory and practice, increasing motivation to learn, increasing willingness to solve problems, willingness to work in groups, validating calculations, and promoting the ability to innovate. Through experimental practicals, previously learned theoretical knowledge is tested for its correctness through practical examples, and the content is illustrated more vividly and memorably for students. This makes it easier for students to acquire subject-specific and interdisciplinary skills. Even if virtual learning (e.g., virtual reality experiments) has benefits for students, real experimental practical courses play an indispensable and important role, especially in engineering studies.

The subject area of dynamics (e.g., vibrations, acoustics) is perceived by students as interesting, but difficult at the same time. This is often due to the lack of the so-called "dynamic feeling" about vibration and acoustics. This feeling must first be formed and developed through cognitive learning. In order to make the basics of vibrations better and more vivid for students, the Chair of Dynamics and Mechanism Technology has procured seven "Engineering Suitcases for Sound and Vibration Analysis". In the following article, a brief overview of the possible applications of the suitcase will be given, as well as initial experiences with the Experimentalpraktika@home and approaches on how to effectively use them will be presented.

2. Concept of the engineering case

The experimental cases enable simple vibration and acoustic measurements to be carried out. These can be done on machines, vehicles or structures. With a useful frequency range of the data recorder of up to 20 kHz, the complete vibration and acoustic frequency range is covered. In particular, it is intended to give students the opportunity to learn how to use professional measurement technology by carrying out measurements themselves, to validate a finite element method (FEM) calculation and to gain a better understanding of the material and calculation models. This gives students the opportunity to deepen and expand their technical and experimental skills.

Fig.1: Engineering case

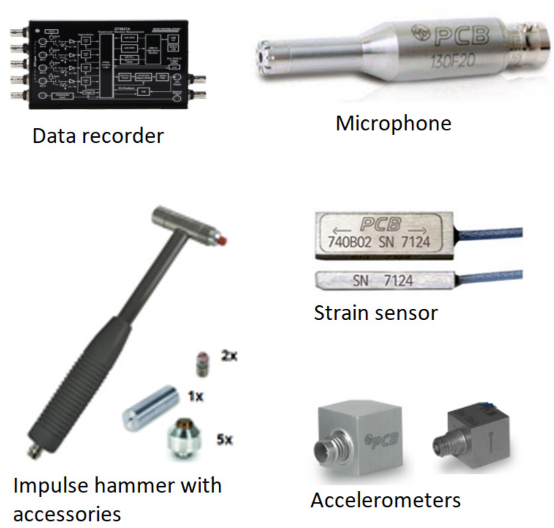


Fig.2: Components in the engineering case

The central component of the case is a 4-channel data recorder that can also generate signals. To be able to measure mechanical vibrations, two uniaxial and one triaxial piezoelectric accelerometers are provided. Strains, which can also serve as measurement variables for mechanical vibrations, can be measured with the enclosed strain sensors. Finally, two microphones enable the measurement of airborne sound, which often occurs alongside mechanical structural vibrations. All sensors (incl. microphones) are piezoelectric sensors with built-in electronics, so-called IEPE (Integrated Electronics Piezo Electric) or ICP (Integrated Circuit Piezoelectric) sensors. Thanks to the integrated signal conversion, such sensors are easier to handle and less sensitive to electrical interference.

An impulse hammer with an integrated force sensor can be used for controlled excitation of vibrations.

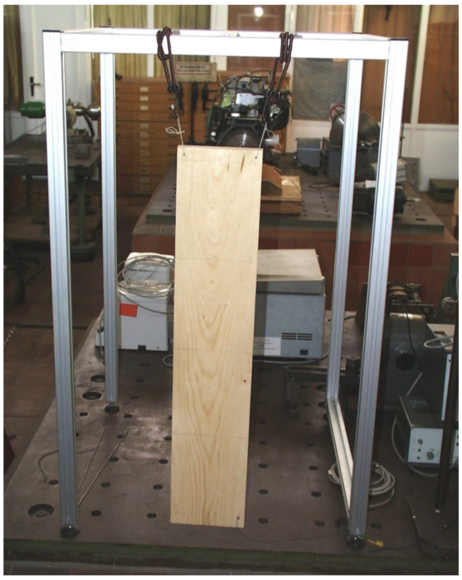
The PC-based data recorder is connected to a computer via USB. Additional signal conditioning is not required for the use of common sensor technology. With the associated software, the unit can be used to record and display measured values, as well as save them to the computer's hard drive. In the frequency analysis mode of the software, analyses such as spectrum, auto spectrum, power spectral density, window weighting and digital filtering can be performed. In the extended mode, spectral analyses can be carried out over two signals, such as the determination of transfer functions, cross spectra as well as coherence functions. The unit can also be used under all common measurement technology applications such as LabVIEW, Matlab, Dasylab or Visual Studio. In particular, the programmability with MATLAB as well as common programming languages such as .NET and Python allow students to combine measurement and analysis tasks and to deepen and expand their knowledge of hardware, measurement process and data processing. Finally, it creates the opportunity for the user to develop new applications and thus promote innovation.

Since several data recording devices can be coupled together, more complex measurements can also be carried out by combining the content of more than one experimental case.

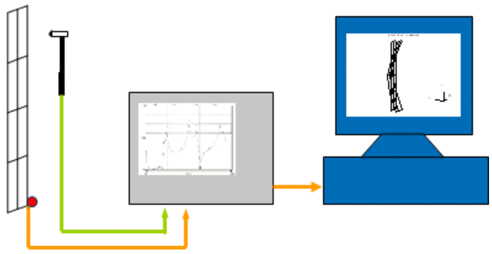
3. Application in teaching

In the summer semester 2020, the students were able to borrow the experimental cases for the first time in the course "Experimental Modal Analysis" and experiment with them at home. First, the theoretical knowledge of vibration analysis and modal analysis was taught by online lectures. The students were able to understand the learning material and internalize the theory through exercises and discussions in question-and-answer sessions. However, the experimental practical course that normally accompanies lectures could not take place on site because of the ban on face-to-face lectures. This was compensated by handing out the cases to the students.

From the end of May, limited face-to-face teaching was possible again. In the first classroom session, a demonstration experiment was conducted on the vibration analysis of a coated wooden panel (Fig. 3).



a) Measurement object



b) Measuring chain

Fig. 3: Measurement setup for modal analysis of a wooden panel a) Measurement object b) Principle measurement setup

The students thus got to know the practical procedure. They were allowed to work with the measuring equipment such as different measuring sensors, excitation devices (e.g., modal hammer of different sizes 5 g - 10 kg, vibration exciters of different types), touch the measured object and feel the vibrations up close. This facilitates the understanding of the theoretical basics as well as the development of a "dynamic feeling".

With experimental modal analysis the so-called modal parameters, such as natural frequencies, natural damping, and natural modes of vibration of a structure can be obtained through testing. The main objectives of experimental modal analysis are, for example:

- Detecting and avoiding mechanically or acoustically disturbing resonances
- Comparison of the results with the calculated vibration behavior from numerical simulations, such as the finite element method (FEM), in order to check the assumptions about geometry, material parameters, calculation model, etc. necessary in the calculation and, if necessary, to correct them until satisfactory agreement with the experimental results is achieved.
- Derive constructive measures to change natural frequencies if excitation frequencies cannot be influenced.

In the second classroom session, a somewhat more complicated measurement object was analyzed. The possible resonance frequencies of a block foundation (Fig. 4) as well as their natural vibration modes are to be determined. This task has great practical significance, as foundation vibrations have a great influence on the precision and service life of machines as well as the well-being of an operator. More complicated measurement objects (car body and tram structure) were not used this semester, as it was impossible to carry out an experiment due to the applicable distance and hygiene regulations.

Fig.4: Determination of the natural frequency of the block foundation.

After the two introductory experiments, the briefing on the engineering case took place once again in summary. This included the explanation of the calibration documents, the set-up of the measurement chain, the software installation, the setting/operation of the measurement software up to the complete measurement. Six students were each handed out an engineering case.

With the engineering case manual written especially for our students, they were provided with even more extensive learning material for reference and self-study. The manual begins with an introduction to measurement technology, especially measurement technology in engineering, as well as practical tips on measurement technology. After the detailed description of the contents of the case, the possible uses of the hardware and software are presented. Particularly helpful for students are the detailed step-by-step instructions for various usage scenarios, such as recording the time course of vibration quantities, using measurement triggers, ad-hoc frequency analysis, determining the transfer or coherence function, controlling the excitation signals as well as evaluating and interpreting the measurement results, etc.

With the mobile engineering case and the basic theoretical knowledge, the students are to be enabled to independently conceptualize, prepare, and carry out a self-selected experiment in the field of acoustics and vibration engineering. The aim is to promote experimental skills such as the conception, planning and recording of series of measurements, plausibility checks and evaluation of experimental data within the framework of the task processing. At the same time, subject-related knowledge is deepened through measurements, processing of measured values and interpretation of results.

The students had 2-3 weeks for their experiment, after which an investigation report was to be submitted.

4. Supervision concept

The home internship requires a high degree of self-organization and self-discipline on the students' part. But it does not mean that the students are completely on their own for the home practical. A wide range of support is available to the students for the conception, preparation, and implementation of individual experiments. Specially adapted learning materials are provided. In addition, digitalization makes a multimedia supervision concept possible, which consists, among other things, of the elements of forums, chats, learning videos, video conferencing, etc. Outside the classroom, students can get in touch with the lecturer or supervisor to discuss the learning materials, gaps in knowledge, technical questions or problems that arise. Communication usually takes place via OPAL forums, chats, e-mail or even by telephone. Depending on the urgency of the problem, questions are answered via e-mail, forums or video conferences are organized. Through (asynchronous) discussions and/or video conferences, questions and problems are identified, solutions are shown, and the work processes are reflected upon.

The supervisor kept one case in order to be able to follow up on any technical problems the students might have and to help with online support step by step.

5. Results

One among six students admitted that he had not done anything with the case. He justified it by saying that he did not want to take time for it this semester because he had learned that, according to the examination regulations, he could not obtain credit points through this subject.

Three students stated that they had examined corresponding test objects with the measurement technology, but they did not want to prepare a test protocol due to time constraints. They reported orally on their test object and their experiences at an attendance meeting. The protocols finally submitted by the remaining two students were of high quality. Both students had chosen a small table as their test object.

In the experimental protocols, the experimental concept and the experimental set-up were documented in detail, the measurement results obtained were interpreted and an error analysis was carried out. In addition, the students voluntarily compared their measurement results with FEM simulations to verify and validate the simulation model (Fig. 5).

The comparison of the experimentally determined modal parameters with the calculations shows that the calculation does not quite match the measurement result. Therefore, a search for the cause and discussion of various questions regarding the calculation and the experiment was carried out, e.g.

- Are the results plausible? The plausibility check is a basic tool with which calculation or measurement errors or interpretation problems can be detected.
- Is the FEM model, the material parameters and geometry, correct? Were the special properties of the wood material (plastic, lightweight material, ...) sufficiently considered in the modelling? Are my FEM calculations therefore trustworthy?
- Are the boundary conditions, e.g., storage of the test object, suitable?
- Are the excitation forces in the vibration test sufficient and suitable?

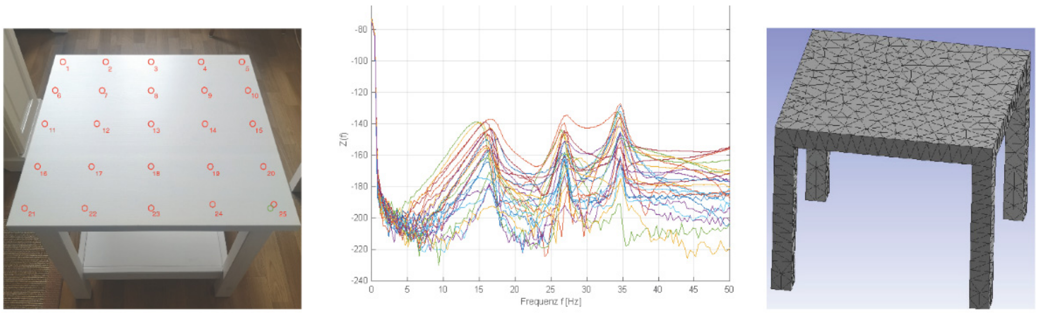


Fig. 5: (left) measured object and measuring points, (centre) measured frequency responses, (right) CAD/FEM model (evidence from student L. Hollas and V. Scholz)

- Are the components of the measurement system (transducer, shaker, modal hammer, data acquisition device, amplifier, cables, etc.) matched to each other for the experiment?
- Is the experimental setup and the measurement chain, correct?
- Are the measurement data evaluated correctly?

In a feedback discussion, the students stated that they had expanded their competence about scientific thinking and empirical work through the experimental internship.

6. Advantages and disadvantages

The shift of university teaching from the lecture hall to the digital space due to the Corona pandemic, as well as the strict hygiene rules, mean that the internships cannot be carried out in the classical form. Even though the home internship arose out of necessity, many advantages seemed to speak in favor of such practicals@home:

- Flexibility in terms of time and space, as the acquisition of knowledge is not bound to fixed dates but is possible at any time. This makes it possible to learn according to one's own rhythm without having to coordinate with lecturers or other participants.
- Free choice of learning speed and intensity: Students can decide which and how much information they want to absorb at a time, i.e., how quickly and intensively they want to learn - for example, whether they want to repeat a particular experiment in full or only in part.
- Retrieve additional information according to individual needs and demands without having to absorb information that is not of interest to them.
- Digitalization enables good communication with supervisors and group work between fellow students.

Another significant advantage of the home practicals is that the measurement objects are usually authentic and close to reality, (such as a small table here). Other possible measurement objects would be, for example, the vibration behavior of one's own car or the floor load caused by a spinning washing machine. The motivation for the practical courses increased. The students are given freedom to realize their own creative ideas. From the reported results, it can be seen that most students were very motivated for the home practical, although the quality of the submitted protocols has no direct influence on the grade.

Nevertheless, our pilot test shows a sobering result, at least partly. The opportunity offered does not necessarily lead to better learning competence and more knowledge. Conducting experimental trials without direct assistance from lecturers may promote students' independence, but can be demotivating for others because of the lack of opportunity for immediate queries. Misinterpretations and errors are rarely detected and in the worst case prevent learning success. In addition, uncertainties and irritations are not absorbed and can therefore lead to frustration in the long run. Creative problem-solving dynamics, which often arise in face-to-face events, also do not come about in this way.

Another very general problem is: Not all students are willing to take their learning into their own hands. Learning at home requires a high degree of self-discipline, which not everyone is able to muster [2].

Of course, the problems mentioned here do not mean that the advantages presented earlier are not valid. It is clear to us that the home internship needs to be complemented: It must be coupled with face-to-face teaching or at least video conferencing. The combination of home practicals and various video conferences/presence teaching can also compensate for the didactic problems typical of self-learning. Even after the pandemic, the home practicals can be a useful and promising additional offer, but not a substitute for the on-site practicals.

Another problem for home practicals is the increased wear and tear on the measurement technology, which is associated with increased operating costs and the need to purchase replacements. Both the measurement technology such as sensors and the accessories such as various cables and adapters are sensitive to improper mechanical stress. The first small damages have already been detected. The reasons for this can be many and varied. On the one hand, the individual components in the engineering case are not built robustly and hard-wearingly, on the other hand, the students still lack the experience to handle sensitive measurement technology despite detailed instruction. Gaining this experience, however, is precisely one of the learning objectives of an experimental practical.

7. Conclusion

The first pilot for home internships has provided important insights for future implementation. Home internships can offer motivated students a great opportunity to apply their acquired knowledge and implement it across subjects. In addition, home internships strengthen their independence and action orientation. Students' self-discipline, learning organization, time management and, finally, motivation influence the outcome of home placements, with motivation being the most important factor for success. It is crucial to find ways to increase motivation.

Various didactic methods were used to increase motivation, for example, within the framework of the course, students were given the opportunity to complete their tasks under their own steam and thus to perceive their own actions as effective and efficient (experience of competence). They were given the freedom to decide for themselves which test object they would like to examine, to what extent they would also deal with the topic in an interdisciplinary way, and to design their experiments in such a way that an optimum is achieved in terms of task completion (autonomy), and the feeling that they have something very practical and important to do (meaningfulness) [1]. This requires structured planning of the course, the task, and the learning objectives. The lecture and the theoretical exercises must be coordinated with the assignment in such a way that the tasks for home practicals are challenging and at the same time manageable. The necessary preparation, or any problems that may arise during the execution of the experiment, should be discussed in advance in an attendance round, so that the students are not overwhelmed during home practicals and enjoy the tasks on their own initiative. In addition, they should know exactly which contents are important, which learning objectives are to be achieved in each practical (transparency). Prompt (online) support should be guaranteed for technical and methodological questions.

The additional activation of extrinsic motivation, i.e., motivation based on incentive from outside, is also useful, as not all students have the intrinsic motivation for their work. This is true because the decision for the subject is often stimulated to a certain extent by extrinsic factors, since the course "Experimental Modal Analysis" has a very high practical relevance and is an essential mainstay compared to computational simulation. A possible incentive would be to anchor additional bonus points for the practical courses in the module assessment. The bonus scheme offers students an incentive for continuous learning during the semester and thus promotes better learning. For example, students can earn an 'extra' for the upcoming exam through graded homework or experiments. However, this must be provided for accordingly in the examination regulations.

8. Outlook

The first impressions formed make it clear that Experimental Practicals@home bring a special added value for the acquisition of competences. In the future, the engineering cases will be used in addition to the subject "Experimental Modal Analysis" in other courses such as measurement processing and diagnostics and vibration theory.

With the commencement of the new study and examination regulations, students of the specialization "Simulation Methods of Mechanical Engineering" and "General and Constructive Mechanical Engineering" will also attend the above-mentioned courses from the summer semester 2021, thus increasing the need for engineering cases. The Chair of Dynamics and Mechanism Technology is endeavoring to purchase additional cases and software, as well as to provide funds for corresponding operating costs.

Acknowledgements

The seven "Engineering Suitcases for Sound and Vibration Analysis" were financed with ZUK funds to support teaching.

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