

## REMOTE LABORATORY EXPERIMENTS: FAN MAP GENERATION AND AIRFOIL FLOW CHARACTERIZATION

Konstantinos Eleftheriou  
Aristotle University of Thessaloniki  
elefthkd@auth.gr

Theofilos Efstathiadis  
Aristotle University of Thessaloniki  
theofil@auth.gr

Anestis I. Kalfas  
Aristotle University of Thessaloniki  
akalfas@auth.gr

### ABSTRACT

This paper presents the procedure followed to conduct two various experiments as part of the ‘Mechanical Laboratory’ course of the Mechanical Engineering department, at Aristotle University of Thessaloniki, during the Covid-19 period. Adapting to the personal contact restrictions imposed by the health issue outbreak, a remote experimental method is proposed. In the first experiment, the students had to generate the operational map of a cooling computer fan while on the second one the characteristic parameters of a symmetric airfoil needed to be measured. Multifunctional control panel interfaces were introduced to the students. Through these applications, the student had the opportunity to run the experiments, assess the raw data, monitor all the necessary flow parameters and acquire the important variables. The students had to post-process the results and submit two reports, one for each experiment. This teaching method provided the students with the experience of real research project and guided them to use modern tools to enhance the quality of their future work. This publication focuses on the address of the challenges, arose during the automation of the experiments. The remote experimental sessions indicated some advantages in learning procedure which was also reflected on the assignment grades. The development of the procedure has been successfully implemented and tested over a couple of years while the quarantine measure have been in place. Furthermore, the experience gained will be used to implement modern communication protocols in the experimental set-ups.

### NOMENCLATURE

ECTS: European Credit Transfer  
and Accumulation System  
 $\Delta P$ : Pressure Difference

### INTRODUCTION

An important part of modern mechanical engineering courses is learning through experiments [1]. Experimental concepts support students to build a robust background in understanding of

engineering principles, gain hands-on experience and enhance their problem-solving ability. However, there is a number of limits in using this particular educational method [2]. It is quite expensive for a university to maintain a facility in which students can conduct educational experiments. The number of equipment and the size of the infrastructure needed could make quite difficult to organize student laboratories [3]. Thus, academics have to implement modern tools to create cost effective, interactive and user-friendly labs. Remote laboratories has the potential to solve all the aforementioned restrictions and to become a prime educational method in engineering courses [4].

Remote laboratories have a number of assets which make them quite attractive educational method for the universities. The cost of a well-organized remote experiment is low, so no big investment is needed [5]. Furthermore, most of laboratories do not have enough space to move around which makes the access to the disable students quite difficult. However, this issue can be solved with remote laboratory [6]. Moreover, the students have the opportunity to explore the concept, changing the different parameters of the experiment and deeply understand the under investigation phenomena. Finally, the results of a remote experiment come from a data acquisition system. This means that the students will process real data, facing all the uncertainties of a physical process [7].

Mechanical engineering courses have to incorporate modern tools and new methods to enhance the educational level that is provided to the students. There is an intention of replacing the traditional labs with simulations and virtual labs. This is very difficult though because a physical phenomenon which is approximated by a model can not reproduce every aspect of the real process. Thus, the solution between virtual and traditional labs is the remote experiments [8]. However, a lot of attention needs to be paid to improve the learning procedure from the a pedagogical aspect. Based on the pedagogical science, the most important characteristics of a well-organized remote lab are the visualization and the interactivity.

In mechanical engineering studies and especially in aeronautical experiments, a system response analysis is conducted in various output signals (such as pressure, velocity etc.). These signals have such a frequency response that is impossible for a human to read them. Thus, a visualization panel, where the necessary acquired signals will be plotted, is very important for a remote experiment [9]. Simultaneously, remote lab needs to be interactive. This means that the student can monitor any change introduced by the user. As a result, the student can instantly observe the system response, interact on the changes and understand the under investigation phenomenon better. Generally, interactivity keeps the students' interest very high, helping the learning procedure incredibly [10].

The education community and specifically the engineering one widely accepts the significance of the visualization and the interaction on the learning process. However, their implementation is not something trivial. To build real time monitoring applications, adopting visualization panels and interactive features, requires advanced programming background [11]. Professors are not often software experts and are facing a number of issues trying to incorporate advanced visualization applications into their remote experiments. Moreover, remote experiments can be even more complex considering the different device network protocols and programming languages.

Lazar and Carari [12] proposed a method to develop a network control system using LOOKOUT SCADA, a software created by National Instruments. In this remote lab, the student can design and use a control system to operate a real pilot plant thought internet. Gomes and Bogosyan [13] analyzed the modern practices in engineering remote laboratories. The different components, software platforms and learning management systems for remote experiments were deeply described. A web-based remote experiment is presented by Calvo et al. [14]. This remote lab was used for a control engineering course.

This work presents two remote experiments which were conducted as part of a mechanical engineering course. The evaluations of the learning process showed positive student feedback and good learning performance.

## COURSE STRUCTURE

'Mechanical Laboratory' is a core course which introduces the students to measurement technics in every aspect of mechanical engineering. Specifically, there are 10 different topics and the students have to select 5 of them. They have five-hour lecture per week, where the theory of the topic is analyzed, 15 hours in total per individual topic and a three-hour experimental session, where the experiment is conducted and the data is collected.

Two out of ten topics are related to aeronautical engineering. The first one is called 'Flow around an Airfoil' and the second one 'Fan Characteristics'. In both topics, the systematic approach of measurements is emphasized and its relationship with the profession of a mechanical engineer is presented. Furthermore, the course focuses on the ways to incorporate computers in experiments, introduces the working principles of the measuring devices and specializes in statistical methods for data post-processing. Simultaneously, the design of an experimental set-up, the accuracy of the sensors and the repeatability of the experiments are in detail examined. Finally, systematic and random errors, signal acquisition and signal processing are analyzed.

The general objectives of the course are to acquire, process and explain the physical meaning of the experimental data and apply modern laboratory methods where it is possible. Table 1 shows the course structure based on the deferent activities that the students have to perform to successfully complete the course. Furthermore, the estimated workload and the ECTS for each individual activity is noted.

Table 1: Course structure

Activities	Workload [h]	ECTS
Lectures	75	2.50
Experiments	10	0.34
Technical Reports	60	2.00
Oral Exam	2.5	0.08
Written Exam	2.5	0.08
Total	150	5

## Technical Reports

After collecting the data from the deferent experiments, one technical report for each of them needs to be written. In these exercises, the students have to process the experimental results and capture all the physical phenomena that have been taught. Regarding the two aerodynamic written assignments, the students have to answer a number questions. In the 'Flow around an Airfoil' experiment, there are different aerodynamic plots that the students have to produce such as the pressure distribution around the airfoil for different angles of attack. They also have to calculate the airfoil lift and drag coefficients. Finally, they comment on the results to understand the physical phenomena like separation flow. The technical report of the 'Fan Characteristics' experiment includes the generation of the operational map of the tested fans, the velocity calculation using the pitot tube working principle. Specific attention is paid in understanding the surge mechanism of the fan using the data.

### Oral Exam

As part of the course, a compulsory oral exam needs to be taken. The main learning outcome of the course is for the student to understand the different phenomena through the experiments, to realize the importance of the laboratories in research work and to process real experimental data. Therefore, by the oral exam the students can briefly explain the experimental set-up, the sensors used and the data that they acquired and the conclusions they came to. Furthermore, there is a quick discussion, where the students can give some feedback on the lab experience and propose their own idea for future development.

### INTRODUCTION OF THE REMOTE ACCESS EXPERIMENTS IN THE COURSE

A remote laboratory is typically a control panel from which the user can run an experiment (fig 1). The initiative for the development of remote labs was due to the COVID-19 restriction, which made the lab access impossible. A remote experiment needs to have some important features. It is necessary for the user to have a visual view of the experimental setup. This means that cameras, looking at the set-up, have to be used. Furthermore, all the sensors have to be connected to a single computer to ensure the synchronous measurements. Also, all the moving parts have to be controlled remotely using a control panel. Lastly, the acquired data have to be assessed before being saved. As a

result, a plot of some critical values is quite significant.

### FAN MAP GENERATIONS LABORATORY

#### Experimental setup

The experimental setup essentially consists of an open tunnel where the velocity and the static pressure difference  $\Delta P$  can be measured. The tunnel is made of plexiglass and has circular cross section. In the middle of it, a two-stage fan is been placed. The static pressure difference before and after the fans is measured. To make that measurement, there are 4 holes, placed every 90 degrees, upstream and downstream the fans, where some small cylindrical metal tubes with a diameter of 1mm are placed. The pressure is finally transferred to a digital micromanometer (Netscanner) through some rubber tubes. The data is collected in real time using a Labview script.

At the outlet of the wind tunnel, there is a cone with which the outlet surface is adjusted. The cone body can be inserted into the cylindrical tube of the wind tunnel with the help of a step motor. The role of cone is to change the mass flow rate of the air entering the system. When the cone is completely outside, the maximum mass flow can run the system.

After the inlet there are the, so-called, flow straighteners. This is nothing more than tubes of smaller diameter which remove the twist from the fluid which may have been introduced by the shape of the inlet. This device is used because the

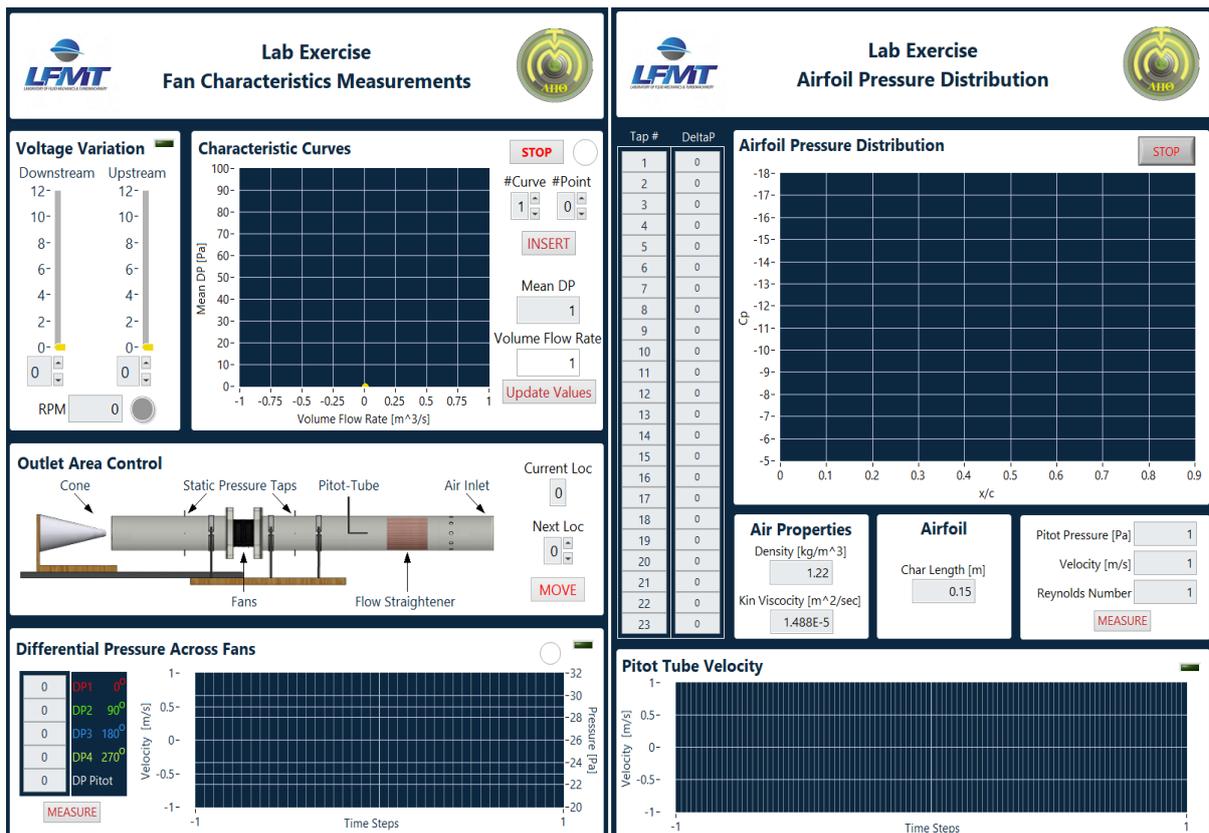


Figure 1: Control Panels for the remote experiments

freestream velocity needs to be measured. So, the flow has to be smooth in order to have a valid velocity measurement. The velocity is measured using a Pitot-tube.

### Equipment

**Piezo-resistive Sensor:** There is a thin diaphragm which is made of silicon and in which resistances are placed. If there is a pressure difference  $\Delta P$ , the diaphragm expands, causing a distortion in the resistances. They react to the deformation, creating the piezoelectric effect that changes the electric voltage. Through calibration process, these voltages can be converted to pressure values. So, the pressure is not measured directly but through the voltage difference across the resistances.

**Pitot-Static tube:** This is a device which measures the flow velocity. It uses the pressure gauge, measuring the dynamic pressure (the difference between total and static). To use the pitot-tube, the flow needs to be steady and incompressible. Also, it needs to be placed in parallel with the flow stream lines and its diameter should not be comparable to the size of the wind tunnel.

**Fans:** There are two computer cooling fans consisting of 7 blades which are located in series.

**Digital Tachometer:** A tracker sensor measures the rotational speed of the rotor using an optical encoder.

**Step Electric Motor:** To adjust the position of the cone a step motor is used. It works using the principle of the attraction of magnetically opposite poles. Generally, the more windings there are, the smoother the movement.

**Arduino Controller:** To control the different devices of the experiment through a computer, Arduino controllers and motor shield cards are used. The communication protocol is programmed in LabView.

**Cameras:** Two cameras are used to have a visual view of the experiment and especially of the cone position.

### Software

During the experiment, the main control panel needs to be prepared. The LabView script consist of the following four windows:

**Fan Control (Voltage Variation):** There are two control bars, as showed in figure 2, with which the supplied to the fans voltage can be chanced. The downstream bar controls the fan which is closer to the cone, while the fan, closer to the pitot-tube, can be controlled by the upstream bar. The green light indicates continuous communication with the computer and the fans. This light is quite important because it is a way to confirm that there is no issue with the fans. The fan speed index indicates the rotational speed of the fans in RPM and is taken as the same for both fans.

**Cone Position Control (Outlet Area Control):** The free cross-section decreases with the introduction of the cone. Current Location indicates where the cone is in real time, Next Location indicates the desire location that the user wants the cone to be, and Move activates the motor (fig 3).

**Recording of the Results (Differential Pressure Across Fans):** This window has the 3-second average pressure values on the left hand side and the velocity time series values on the plot at the right hand side (fig 4). Measure button starts the acquisition. The raw data are saved in an excel file. The name of each file contains the basic characteristic of each measurement like cone location etc.

**Visualization and evaluation of the results (Characteristic Curves):** The Curve indicator shows the characteristic line number of which the data is recorded, Point indicator is the number of current cone position and Mean DP is the average value of the four pressures displayed in the results window. Update Values button fills in the Mean DP and the Volume Flow Rate while Insert introduce the acquired data point into the chart. In figure 5 apart from the window structure, an acquired data-set is plotted.

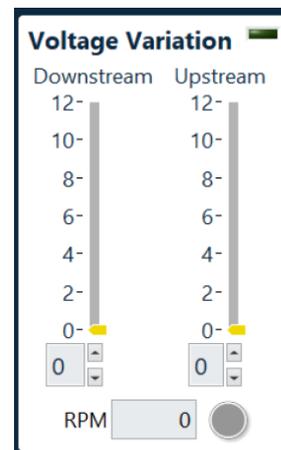


Figure 2: Fan Control Window

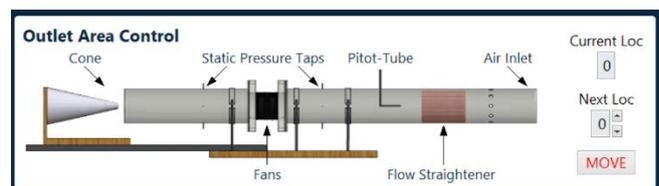


Figure 3: Cone Position Control Window



Figure 4: Recording of the Results Window

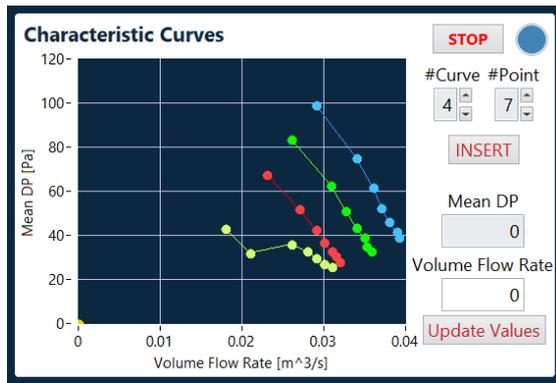


Figure 5: Result Visualization and evaluation Window

## AIRFOIL FLOW CHARACTERIZATION LABORATORY

### Experimental setup

The experimental setup consists of a suction open wind tunnel running with a centrifugal compressor and a wing which is located in the test section. The speed of the wind tunnel can be controlled with a manual valve which is placed at the end of it. Only one speed is tested, thus the valve is always locate at one position. Regarding the wing, it has a NACA-0012 airfoil, made of wood and has 23 holes. The taps are located in the midspan in a way that the whole cross sections is equally covered. This holes are connected with the pressure scanner via rubber tubes. The wing is connected to a step motor and can be rotated to different angles. Seven angles of attack are tested (from 0deg to 15deg, steps of 2.5deg). Last, there is a pitot-tube which measures the freestream velocity in front of the wing. All the devises are connected to the computer which controls the experiment and acquires all the necessary data.

### Equipment

The sensors, the step motor and all the required equipment were described in the previous section.

### Software

*Setup and Control Window:* In this part of the panel, there are three different windows (fig 6). The first one, starting from the left, has the air properties which need to be input by the user. The next one is related to the airfoil. The user have to insert the wing characteristic length and can change the wing angle of attack using the up/down arrows. Finally, the last window has indicators for pressure and velocity of the pitot tube as well as the Reynolds number. The **Measure** button starts the acquisition of the data.

*Timeseries Velocity (Pitot Tube Velocity):* The differential pressure across the pitot tube is converted to velocity in real time and plot in the chart. The data acquisition starts when the pitot tube velocity is steady.

*Airfoil Results Visualization (Airfoil Pressure Distribution):* This window has the plot of the airfoil

pressure coefficient. The plotted data is a 5-sec average of the raw data. The advantage of this plot is that the user can observe any change on the shape of the pressure line, can recognize the pressure and suctions sides of the airfoil and could realize when the wing is under stall condition. In figure 8 the pressure distribution at 5deg is presented.



Figure 6: Setup / Control Panel Window

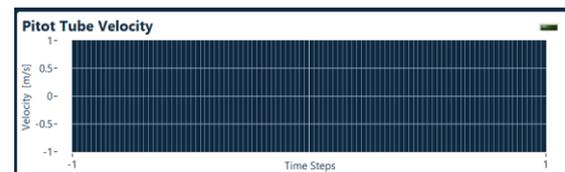


Figure 7: Timeseries Velocity Window

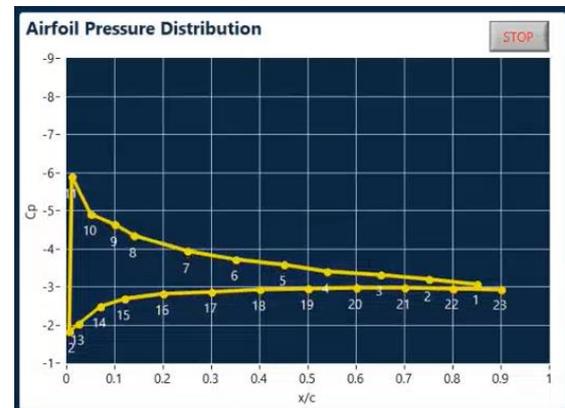


Figure 8: Airfoil Result Visualization Window

## EVALUATION

In this course, the student feedback policy is adopted. During this procedure, the students had the opportunity to give their impressions on the course outline and to make any suggestions to improve the course. The evaluation assessment included a survey in which the students had to answer anonymously some questions. The questionnaire was taken at the end of the course. It covered a variety of topics such as the structure of the course, the quality of the remote experiments, the technical reports and the oral exams. The given feedback was encouraging and the suggested changes were quite useful.

The students seemed to be satisfied with the support provided by the professor and the experimental team. 72% gave a positive feedback on the way that the course and the experiments were presented as figure 9 shows. However there were some different answers regarding the oral exams. 49% of the students thought the oral exam can be covered by the written exam while 41% agreed on its existence. 59% of the students stated that they

learnt the operational principle of the sensors through the experiment (fig 9). The majority of the students (60%) were positive that the workload was very high and that it was quite challenging handling 5 experiments, 5 oral exams and 5 technical reports. However they agreed that the provided knowledge was in line with the course syllabus. Furthermore, they stated that the content of the experimental case studies and the technical reports helped them to understand the objectives of the course. They voted that the experimental results and the experiment itself helped them to understand the surge and the stall conditions of the fan and the wing, respectively.

Part of the evaluations was also about the role of the control panels in running the experiment remotely, visualizing the results and acquiring the data. All of the students voted that the digitalization of the experiment using the control panels was a novel concept, following the current norms of the digital world, and made the experiment more helpful and interactive. Figure 10 shows that 94% of the students very quickly understood how to use the app. Furthermore they said that it was entertaining to operate an experiment through an application and made the whole learning process attractive. They liked the remote experiments however some of them felt that they missed the lab experience. Finally, the students realized the advantages of the remote experiments but the majority of them were neutral in conducting all the laboratories remotely.

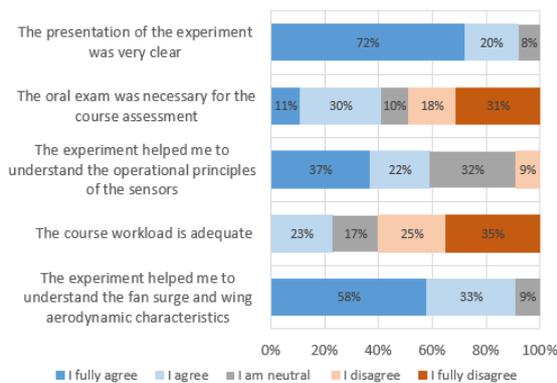


Figure 9: Student evaluation of the experiment and the course structure

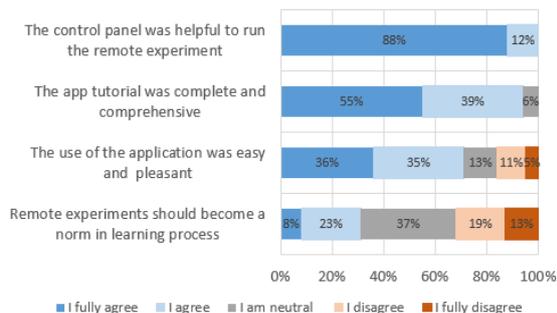


Figure 10: Student evaluation of the role of the application for the remote experiments

Generally, the students gave a positive feedback on the characteristics of the course. Moreover, they stated a lot of their experiences that they gain during the lab and the thinks that impressed them in additional comments. Finally, a lot of them provided potential changes in the remote experiment and aspects that need to be investigated. Some of them are stated below:

‘The virtual lab was an amazing experience. Controlling motors and capturing data from a real experiment was very cool.’

‘It would be nice if we control the parameters of the signal processing through the application in order to have direct access on the applied statistics.’

‘Experiments normally should be conducted in person. However, this is a good short-term solution due to Covid-19 and a long-term solution for the disables.’

‘This course lasted so long. Too many technical reports and the workload is almost the same as two normal courses.’

## CONCLUSIONS

This paper presented the introduction of remote experiments in the ‘Mechanical Laboratory’ course during Covid-19. The remote experimental method includes two control panels, the first one for the ‘Flow around an Airfoil’ experiment and the second one for the ‘Fan Characteristics’ lab. A tutorial of the application is given to the students before running the experiments. The students had to run the experiments remotely, visualize and assess the data on the application and acquired them. They also have to write two technical reports base on the data that they captured.

Remote experiments showed, according to the students’ feedback, a positive impact on the learning process. The students understood in a better way complex turbomachinery and aerodynamic phenomena, which is also reflected on the exam results. They got a practical experience on how an experimental study need to be conducted, how can experimental data have to be processed and how the available technology can be merged to create a remote fully automated experiment. This is a quite important lesson for an engineering course and it would be very useful in the engineering career of the students. At the same time, the interactive sense of the remote application made the course more enjoyable which have a positive effect on the learning process.

The course was upgraded, applying digital tools, first of all, to ensure that the experiments will be smoothly conducted and secondly to provide the student with more interesting course. The results showed that all of the students found the remote

control panels helpful. 91% of them understood the course better using this remote application. However, the majority of the students felt that the workload of the course was enormous and they suggested that the oral exam could have been included to the written exam. Generally, the remote experiments had beneficial consequences on the learning procedure.

#### ACKNOWLEDGMENTS

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