IL NUOVO CIMENTO **45 C** (2022) 215
DOI 10.1393/ncc/i2022-22215-4

Communications: SIF Congress 2021

The laboratory in pandemic times: Design and test of a Home Kit

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received 30 January 2022

Summary. — Real experiments play an indispensable role in Physics and Science Education. When designing remote laboratories, teachers have the objective to propose to students significant experiments that allow rigorous analysis. To achieve this goal, a custom kit of "home" experiments has been designed, created and employed with students, suitable for the contents of a Laboratory course. The kit experiments were designed to match the learning goals of a general laboratory course in remote teaching. The kit has been tested with 35 undergraduate students and 50 high school students. Teaching material has been created that can supplement high school teachers in carrying out some activities. Student survey results at the end of the courses indicate that the critical learning goals were met, student satisfaction with the remote lab was maintained, and successful collaboration via video-conferencing breakout rooms was achieved.

1. – Introduction

School and university teaching as well as teacher training have been drastically affected by the Covid-19 pandemic. In the last 2 years, the pandemic has produced global breaks of face-to-face teaching activities, thus for physics instructors [1], a crucial problem concerns remote teaching including experimental work: the impossibility for students to get into the labs and to handle the equipment makes it mostly challenging to adapt to remote laboratory for distance learning [2]. This unexpected shift from face-to-face classes to online lectures caused many challenges for educators, and labs were often modified with limited success [3]. The community of lab teachers had to use innovative and creative approaches to quickly shift their courses to remote mode, while preserving their learning goals [2, 4]. These approaches consist in employing technological equipment like iOLabs and smartphones or sending home kits to students [5], having instructors in the lab manipulate the equipment while students direct them via video conference, using simulations, remote labs and virtual labs to explore phenomena and collect data, sending students data already collected and so on. In this contribution, the application of a cost-effective, home experiment kit for remote teaching of introductory physics labs is illustrated. The kit was designed to match the existing face-to-face lab course learning goals and the general laboratory course learning goals in remote teaching.

In this paper we try to answer this main research question: Can a hands-on physics Lab be delivered effectively as a distance Lab using a Kit?

2. – The Home Kit

In the early phase of the pandemic, to offer hands-on labs at distance, we employed only household equipment (*Kitchen Lab*), Remote Laboratories and Simulations. Obviously, this "kitchen" approach did not allow all experiments to be done and would have produced equity issues for students. A kit that met all learning goals and economic restrictions was considered to be the best solution for the future. The kits in fact are an appropriate and viable instructional strategy for introductory science courses [4]. Since the cost of commercial kits was unaffordable (over 300 euros per student), often with supplementary licensing/content subscription fees, the research group members all agreed upon the fact that this could not be the right solution. Moreover, commercially-available home kits did not include all the tools and supplies needed to perform the experiments usually proposed to students in our lab courses.

In the summer of 2020, our kit (henceforth named the Home Kit) was designed and assembled. As in ref. [5] the Kit experiments were mainly designed to match the existing onsite lab experiments, typically offered to students in the lab courses, but in addition the several components included (Power supply, digital multimeters, diffraction gratings, digital thermometers, Digital Balance, breadboard) can allow, in remote teaching, other experiments typical of a general laboratory course. Since students had to work without being supervised in person, safety was vital in the Kit design, as well as the Kits being robust for ease of use, while the design should make it possible for students to run entire labs by themselves. The experiments that students performed at home by employing the Kit concern a large collection of topics, from classical mechanics (Hooke law, Galileo' study on projectile motion) to thermal phenomena (specific heat, Newton cooling law, thermal equilibrium), from electric circuits (Ohm's law, RC, LED characteristics) to geometrical and wave optics (Snell law, Beer Lambert law [6], groove densities measurements for a diffraction grating, measurements of wavelengths [7], measurements of spectral transmittance [8]) up to Modern Physics (measurements of Stefan-Boltzmann law [9], measurement of the Planck constant with LED [10]).

Apart from the equipment contained in the Kit, students had to use their mobile phones as a pocket Lab (using Physics Toolbox or Phyphox). Smartphones are important educational tools for learning physics (both in presence and in remote teaching) and recently many phone-based experiments have been proposed in physics education (also by using various sensors simultaneously) [11-13]. In autumn 2020 we provided one Kit to each student so that they could carry out laboratory activities within distance learning while collaborating with other students via video-conference. In our design we used the "breakout rooms" functionality of Zoom to let students work in small groups.

3. – Results

The Kit has been tested with 35 undergraduate students and 50 high school students and teaching material has been created that can support teachers in carrying out some activities.

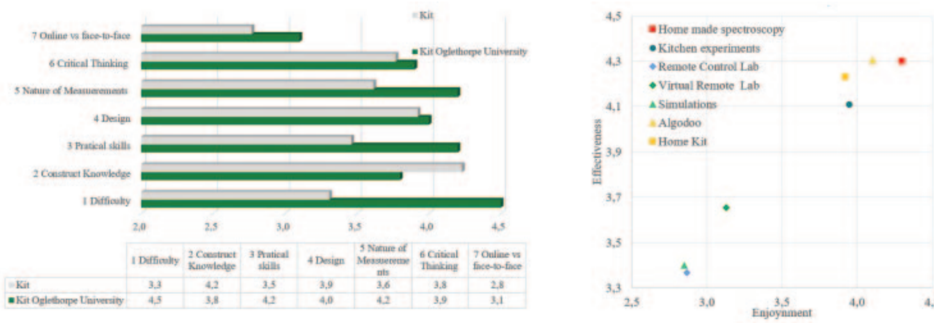
TABLE I. – *End of course survey questions.*

Dimensions - Learning Goals	Questions
1) Difficulty;	Having to do the experiments by myself at home was harder than in a group onsite in the lab.
2) Construct knowledge and a deeper understanding of physics via direct experience;	My experiences with the lab kits will help me apply physics concepts to novel situations.
3) Develop practical skills in running experiments/trials, problem-solving and troubleshooting of experiments;	As a result of running all experiments by myself, I feel I now have better troubleshooting skills for real-world experiment situations.
4) Demonstrate experimental design and analysis of data;	The Kit experiments and extensions helped me learn experiment design.
5) Understand the nature of scientific measurements (repeatability, uncertainty, bias, and precision);	The Kit experiments helped me understand the nature of scientific measurements (repeatability, uncertainty, bias, and precision).
6) Develop scientific habits of mind (critical thinking);	The Kit experiments allowed me to develop critical thinking for laboratory experiments.
7) Effectiveness.	I feel that I learned as much through this online experience as I would have in a face-to-face lab.
For the different activities	Rate the experience in terms of effectiveness. Rate the experience in terms of enjoinment.

At the end of the course, students completed a Likert-scale survey to explore their attitudes about the use of the Kits and what they felt they had learned as a result of having them. Some questions are related to the learning goals which guided the development of all laboratory activities (see table I). With the aim of evaluating the distance learning labs, we analysed the experiences from the students' perspective in terms of comprehension of a phenomenon thanks to the proposed activities (*Effectiveness*), Satisfaction during each laboratory activity and personal interest during the activities (*Enjoyment*). In this case, we asked students to compare different kinds of activities: Home Kit (HK), Kitchen Lab (KL), Remote Controlled Lab (RCL), Virtual Remote Lab (VRL), Simulations (S) and Simulation Software (SS). All the students performed the same experiments belonging to the various categories of remote lab solutions.

In the left panel of fig. 1 average scores are reported for 2 groups of students: the students who used our home Kit and the students of Oglethorpe University who used the kit designed by Howard and Meier [5]. In the right panel of fig. 1 the average scores of effectiveness and enjoyment for the different kinds of activities. In fact, the types of experiments that achieved the highest levels in all three dimensions are those that involve practical work with objects and/or tools and that are carried out individually or in small groups.

Based on the analysis reported in this work we can begin to answer our initial research question: Can a hands-on physics Lab be delivered effectively as a distance Lab using a Kit? In general, we found that the distance laboratory courses had compa-



	1 Difficulty	2 Construct Knowledge	3 Pratical skills	4 Design	5 Nature of Measurements	6 Critical Thinking	7 Online vs face-to-face
Kit	3,3	4,2	3,5	3,9	3,6	3,8	2,8
Kit Oglethorpe University	4,5	3,8	4,2	4,0	4,2	3,9	3,1

Fig. 1. – (Left) Average scores of the survey items; (right) effectiveness *vs.* enjoyment for different activities.

rable final grades and laboratory competencies when compared to previous traditional on-campus laboratory courses. Student survey results indicate that the critical learning goals were met, student satisfaction with the remote lab was maintained, and successful collaboration via video-conferencing breakout rooms was achieved.

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The authors acknowledge the COSID-20 project of the University of Trento which allowed the design and development of the Home Kit which is at the center of this work.

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