Physics Laboratory at Home During the COVID-19 Pandemic

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The pandemic triggered by the SARS-CoV-2 virus has produced worldwide interruptions of face-to-face teaching activity in both schools and universities. In Italy, the quarantine began in the second half of February 2020 and lasted for all the second semester of lectures. The University of Bologna, where all the authors of the present article are based, developed and activated several interfaces necessary to efficiently deliver online teaching courses with the utmost speed. The framework used by the authors is based on a common platform, Microsoft TEAMS, available to all teachers at Bologna University.

The sudden migration from face-to-face classes to online lectures caused many problems for teachers and many more arose for laboratory classes. A key issue was organizing laboratory activities without accessing the labs. In this paper, we describe how we overcame this problem by enabling the students of an introductory physics course in biology to perform various physics experiments at home. Simple experiments, analogous to those that they would have done in the laboratory, were individually conducted by each student, with the online supervision of teachers and tutors. The experiences are characterized by the use of equipment that is commonly available at home or that can be purchased at a low price both in stores and online.[1]

Two basic ideas guided us into formulating engaging home experiences for the students. The first one is to encourage them to use an everyday object younger people are really familiar with: the mobile phone, which is indeed a powerful computer equipped with many types of sensors, including pressure, temperature, acceleration, and magnetic field. The second idea is that the use of expensive equipment is not always required in order to study nature.[2-4]

As a matter of fact, the well-known physicists of the 17th century, Galileo Galilei and Isaac Newton, achieved important results using relatively simple measuring instruments or even rudimentary with respect to those currently available. Furthermore, doing physics with simple tools can prove useful also in ordinary teaching conditions. A longstanding issue with understanding physics is the apparent lack of a relationship between theory and everyday life. “Doing” physics with everyday objects is a means to overcome this difficulty and to make physics less abstract.

In this paper, we describe two examples regarding kinematics and optics. For each experience, the students were provided with a written description and a link to videos presenting the experiment. Furthermore, they were given a list of the required items. All instructional material could be retrieved from IOL (Insegnamento OnLine), the online repository of Bologna University.[5]

Due to the lockdown, we had to take into consideration that a number of students would probably not be able to gather all the items needed to accomplish one or more of the proposed experiences. In light of this, students could retrieve experimental data related to the various experiments, which we collected previously in the laboratory, from the IOL repository. The data were similar to those each student could acquire at home, allowing them to compute, for instance, the values of gravity acceleration, light wavelength, and other physical quantities related to the experiments. Nevertheless, being conscious that a mere data manipulation is not really useful for the understanding of nature, we strongly encouraged students to perform their own experiments and not to simply rely on the available data.

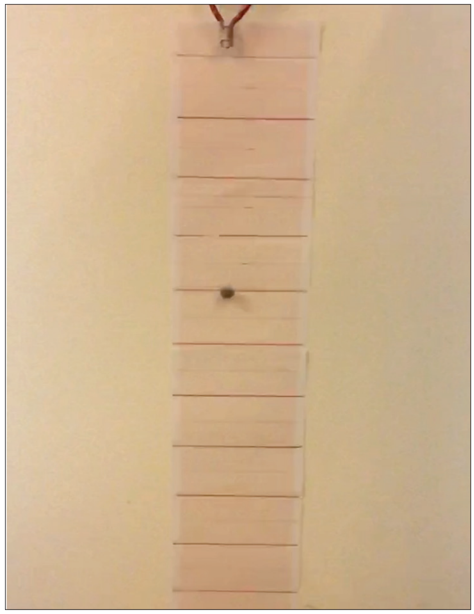

Fig. 1. A frame of the slow-motion video of a free-falling metallic sphere taken by one of the students with his mobile phone and used to compute *g*.

Slow-motion video with a mobile phone and measurement of the gravitational acceleration

A simple yet fundamental experience of kinematics is the measurement of the uniformly accelerated motion of a falling body near Earth’s surface. In order to reproduce this experiment, students were asked to ascertain the position of a small mass falling from about 1 m in height as a function of time. The body can be a metallic sphere, a glass marble, or even a rubber ball. The only constraint is having a negligible air drag. Using the acquired data, it is possible to verify that the body speed increases linearly in time and to compute the gravity acceleration, g. However, this is a difficult task because of the high g-acceleration ($g = 9.804$ m/s^2 is the accepted value for Bologna), which does not allow for the perception of the linear speed increase with the naked eye and easily timing it. The

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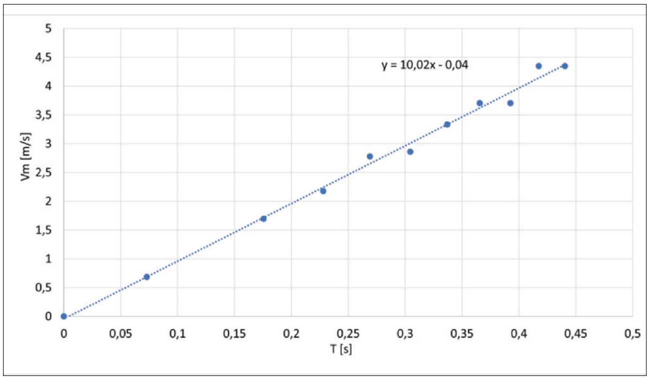

Fig. 2. Graph of body speed, as computed from position and time acquired during the fall. The slope of the interpolation line yields the value of the gravitational acceleration.

question we are confronted with is therefore how to "reduce" the acceleration so that it becomes feasible to measure.

The traditional solution, first used by Galileo,[6] is to use an inclined plane. Help in this direction came from the slow-motion function of students' mobile phones in order to obtain an apparent falling time dilation. This is somewhat equivalent to reducing the g value.[7]

A standard video is made of a sequence of images acquired at 30 fps (frames per second), which is an image every 1/30 s. The slow-motion function currently available in a range of mobile phones allows shooting from 120 to 960 fps. As an example, with a 240 fps, the time scan of images is one about every 4.2 ms, which complies with the required accuracy of this experiment.

The experiment therefore consists of marking sheets of paper with even marks and hanging them on a wall with tape (10 cm is a reasonable distance). Then the video camera is turned on in slow-motion mode, the body is put in front of the marked wall, and it is let fall, as shown in Fig. 1. By using an app (e.g., T.T. Video lite for iOS or KineMaster for Android) to play the video in slow motion, it is possible to perceive the speed increase during the body fall and to record its position and time with enough accuracy.

From this raw data set, each student can obtain the speed as a function of time, computed as $\Delta s/\Delta t$, which is then used to prepare a chart like that of Fig. 2, where the points and linear regression presented by one of the students are shown. A linear fit to the data allows the g value from the slope of the interpolating line to be obtained. Again, the mobile phone can be used by the students to perform the calculus. We described to the students, as an example, the use of the linear fit function of GeoGebra.[8] It is clear that it is possible to directly obtain the g value from the fall time and the starting height of the body. Students were therefore also required to compute g that way and to critically compare the two values.

The relative uncertainty on g is mainly due to that of the slope of the interpolating line. Such an uncertainty, depending on the frame rate of the mobile phone, can easily be less than 5%. Students were also required to pay attention to systematic errors and, in particular, those due to parallax, which is the effect whereby the position of the body appears different from the real one because it is viewed at an angle from the normal to the falling plane.

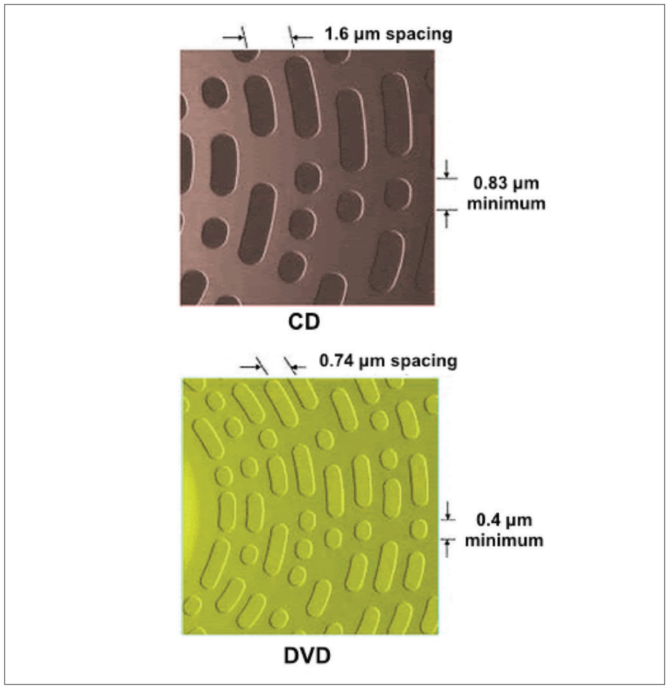

Fig. 3. Sketch of data storage in a CD (top) and a DVD (bottom). The data are encoded in the form of small pits and bumps, arranged as a single, continuous, and extremely long spiral track of data. In the DVD the spacing between adjacent grooves is smaller than in the case of a CD, resulting in a diffraction grating with a smaller *d* value.

DVD as diffraction grating and the wave nature of light

In this experiment, students were required to verify the wave-like nature of light by sending laser light through a diffraction grating and observing how, on a screen placed beyond the grating, a central light spot is produced along with at least two other symmetric spots (on its left and right side). Measuring the position of these maxima also allows the light wavelength to be computed. This kind of experiment is similar to that first performed by Thomas Young in 1801, as a demonstration of the wave behavior of light, the main difference being that he observed the interference pattern produced by a "slip of card" splitting the light passing through a hole in a window shutter. Only later the experiment was done with a double slit.[9,10]

The double-slit interference experiment is relatively difficult to perform, mainly because of the lack of coherence of ordinary light. In order to be able to perceive interference effects, a point light source must be used together with a lens and very thin slits. Nowadays it is possible to remedy these problems using the light emitted by a common and inexpensive laser pointer. Commonly available pointers may have red, green, or blue light (wavelength in the range of 620-650, 530-540, 470-480 nm, respectively).[11,12]

In the proposed experiment a CD (compact disk) or DVD (digital versatile disk) were used as a diffraction grating (see Fig. 3).[13,14] While it is possible to use the grating both in reflection and transmission, we asked the students to work in transmission alone for safety reasons (in order to avoid laser light reflections) and because the setup is simpler (Fig. 4). These optical memories are made of a plastic disk with a spiral groove with a track pitch of 0.74 μm for DVD and 1.6 μm for CD. When light strikes the grooves, it is diffused and at certain angles it is possible to observe the typical pattern of constructive interference. The interference maxima satisfy the simple relation $n\lambda = d \sin \theta$, where n is an integer, λ the light wavelength, d the spacing between grooves, and θ the angle between the direction of non-diffracted light and that of the light towards the interference maxima.

In order to carry out the experiment, the students set the pointer perpendicular to the wall and pointing towards the CD/DVD, which must be in front of the wall and parallel to it. Then the light is turned on and he or she measures on the wall the position of the first order maxima ($n = 1$) projected on the wall to the left and right of the central spot. To improve the resolution, the distance between spots is measured for different distances between diffraction grating and the wall. The tangent of θ is therefore obtained from the slope of the regression line in the plot of half-distance-between-spots and grating-to-wall distance. As in the kinematics experiment, students were required to evaluate the uncertainty on the λ measurements, which mainly depends on that of the spacing between adjacent grooves in the CD/DVD.

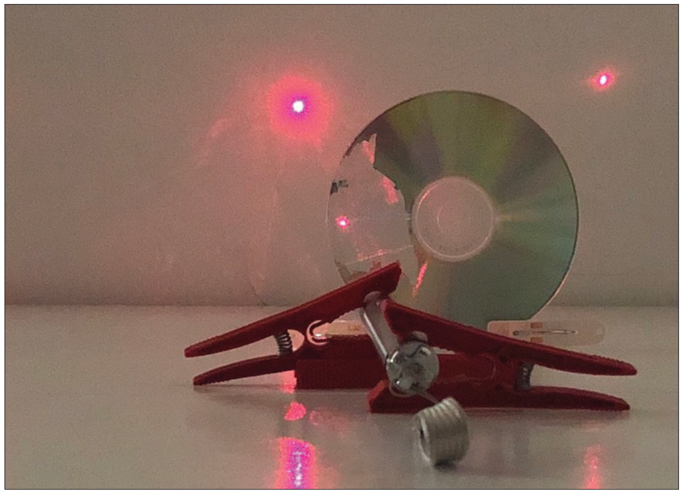

Fig. 4. Setup of the optical experiment, from a picture taken by one of the students. The light emitted by the pointer strikes a CD and is diffracted, producing a central spot on the wall together with two clearly visible interference maxima.

Students' responses to the proposed home experiences

On average, approximately half of the more than 100 students attending the course performed the proposed experiments. The kinematics experiment was accomplished by ¾ of the students, compared to that of optics at ¼. The proposed approach to the laboratory can be considered satisfactory, even if a number of students complained that they were not able to find all the required items and, in particular, the laser pointer. Unfortunately, due to the lockdown, it was impossible to provide all the required tools to the students.

At the end of the course we asked students what they thought about the approach and the experiences. The students' feedback was valuable because we did not initially know how this approach to the laboratory would be seen by students. Some of them even gave suggestions on how to improve the experiments. Here are some representative comments:

- "I was not able to find all the equipment that I needed for the optical experience. For the other experiences it was easier to get all the stuff and so I was able to accomplish them by myself."
- "I succeeded at interacting from home with my mates using TEAMS and WhatsApp, but not so easily as when we meet in person."
- "I personally liked doing experiments at home and finally I did not find it too difficult to carry out them [sic] by myself."
- "The Laboratory is really useful in order to put into practice the concepts introduced during theory lectures, even if the online mode is not like being in a real laboratory."

As shown by these responses, the proposed experiences had a good level of appreciation by the students. Working in isolation at home, even if they were supported online by tutors and teachers, forced the students to think about what they were doing more carefully and deeply than they usually do in the lab. Furthermore, exactly how we had hoped, the use of familiar equipment resulted in a stimulating experience for the students.

The final survey revealed that the large majority of the students was satisfied with the way this course has been taught. Specifically, 79% of the students expressed positive or highly positive feedback. Interestingly, this fraction is remarkably close to the one obtained in the previous academic year, which was 81%. Despite the many difficulties in performing the experiments at home, 91% of the students declared that the suggested and available materials were adequate for the purposes of the course. Again, this percentage is statistically consistent with the one from the previous academic year, which was 93%. Overall, the students stated that the main benefit of the adopted approach was to guarantee the possibility to perform physical experiments even without being able to exploit a real laboratory environment. Obviously, being first-year students, they could not directly compare this home experience with other standard face-to-face teaching activities.

Nevertheless, they suffered to be obliged to work in isolation, without the opportunities, advantages, and fun of working in small groups, as in previous years. This has been only partially alleviated by the use of remote webcam connections and social networks, and it has been perceived as one of the main weaknesses of the adopted approach. For these reasons, however interesting and in this case essential, online teaching cannot replace the "old-style teaching." A direct human relationship with teachers and peers appeared to be an essential component of the teaching process. This study suggests that this is true for physics as it surely is for any other field of study.

References

1. Yunebae Park, *Teaching and Learning of Physics in Cultural Contexts: Proceedings of the International Conference on Physics*

Education in Cultural Contexts, Cheongwon, South Korea, 13-17 August 2001 (World Scientific, Singapore, 2004), pp. 354–355.

2. Andrew Ahlgren, "Apparatus for Teaching Physics: Experiments with simple equipment," *Phys. Teach.* **1**, 78 (Feb. 1963).
3. James L. Hunt, "Five quantitative physics experiments (almost) without special apparatus," *Phys. Teach.* **43**, 412 (Oct. 2005).
4. "10 Ideas for Physics Demonstrations to Use in Your Classroom," Expert TA, http://blog.theexpertta.com/10-ideas-for-physics-demonstrations.
5. Insegnamenti OnLine, https://iol.unibo.it.
6. Galileo Galilei, *Dialogues Concerning Two New Sciences*, translated by Henry Crew and Alfonso de Salvio (Dover, New York, 1954), pp. 178-179.
7. Fábio Saraiva da Rocha, "Using 'student technology' in introductory physics: A comparison of three tools to study falling objects," *Phys. Teach.* **49**, 165 (March 2011).
8. "GeoGebra," Wikipedia, https://en.wikipedia.org/wiki/GeoGebra.
9. Thomas Young, "Experimental demonstration of the general law of the interference of light," *Philos. Trans. R. Soc. London* **94** (1804).
10. Walter Scheider, "Bringing one of the great moments of science to the classroom," *Phys. Teach.* **24**, 217–219 (April 1986). Also at http://www.cavendishscience.org/phys/tyoung/tyoung.htm.
11. Joshua Hadler and Marla Dowell, "Accurate, inexpensive testing of laser pointer power for safe operation" *Meas. Sci. Technol.* **24**, 045202 (2013).
12. James O'Connell, "Optics experiments using a laser pointer," *Phys. Teach.* **37**, 445 (Oct. 1999).
13. Christian Nöldeke, "Compact disc diffraction," *Phys. Teach.* **28**, 484 (Oct. 1990).
14. Alan J. DeWeerd, "CD, DVD, and Blu-Ray disc diffraction with a laser ray box," *Phys. Teach.* **54**, 300 (May 2016).