Physics Education

PAPER

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To cite this article: Margareth K K D Franco *et al* 2023 *Phys. Educ.* **58** 035030

Paper
Phys. Educ. 58 (2023) 035030 (8pp) iopscience.org/ped

Feasibility of teaching experimental physics during Covid-19 pandemic

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Abstract
At the beginning of 2020, the COVID-19 pandemic surprised the world, affecting activities that promote attendance, including abruptly impacting the education area. Educational institutions, from preschool to university, were required to adopt alternative teaching methods to continue their activities. Distance learning has been adopted by educators to address this unprecedented challenge. Our University, more specifically the Department of Physics, reacted to the problem in an ambitious and creative way, taking advantage of it as an opportunity to put into practice methodologies related to the teaching of disciplines that were only practiced in person, such as the discipline of Experimental Physics. This study aims to describe the implementation of the discipline of Experimental Physics I at our University, promoted remotely by professors of the Department of Physics. We verified: (i) that the choice of the best technologies as a tool for teaching is fundamental for the better dissemination of knowledge, (ii) that inclusive programs for each course are very important, (iii) the importance of prior presentation of a schedule, (iv) the importance of defining clear assessment rules for students on remote teaching. We also evaluated the number of accesses as a measure of student participation and analysed the statistics of the discipline in several engineering courses.

Keywords: education, remote learning, experimental physics, pandemic, COVID 19

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1. Introduction

According to the 2018–2019 census carried out by the Brazilian Association of Distance Learning there were about 1800 000 Brazilians enrolled in some form of distance learning (DL) (EAD) in Brazil, 13.5 million vacancies were offered for higher education courses in 2018, of which 7.1 million were for DL and 6.4 million for face-to-face teaching, showing for the first time that the number of DL places was greater than in face-to-face education. For 2019, the DL users represented 43.8% of the total number of students who started in higher education [1, 2].

This educational model, which was already a growing reality in Brazil, has become the only large-scale solution in times of a pandemic due to Covid-19. In early 2020, from basic to higher education, face-to-face activities were interrupted, forcing educators and students to adapt to the use of technological resources in order to continue the learning process. Before the pandemics, remote or distance teaching of the subject of Experimental Physics was not considered. Some courses before the outbreak of the Pandemic planned to introduce alternative learning methodologies [3–10]. In addition, the adoption of new educational platforms is not a mere reproduction of the face-to-face model because it involves the creation of methodologies to adapt to a more current, active and collaborative reality.

In this study we present the elaboration and application of the essentially remote course in the teaching of the subject of Experimental Physics 1, at our University. We describe the scope of the prepared material and the student performance after the end of the semester. We also report the preparation of the experiment in its broad aspects. The aim of this study is to describe the implementation of the course of Experimental Physics I, promoted by the professors of the Department of Physics, remotely. We evaluated the number of accesses and the performance of the students as an instrument to measure student participation and analysed the statistics of the discipline in the various engineering fields.

2. Methodology

The Experimental Physics 1 course is offered every semester by the Physics Department at our University for students (number of students greater than 300) enrolled in the undergraduate faculties in Chemical Engineering, Electrical Engineering, Mechanical Engineering, Industrial Wood Engineering, BioProcess Engineering and Biotechnology, Production and Environmental Engineering. In laboratory classes, in the face-to-face regime, the maximum capacity is 24 students per class.

Before the problem related to the restrictions of social distance caused by COVID 19, the experimental physics courses had an essentially face-to-face mode, since the pedagogical proposal is directly related to the experimentation of the physical phenomena addressed by the students. The didactic physics laboratories used in this course have adequate equipment and physical infrastructure for the execution of practical activities. The experiments were carried out by the students themselves under the guidance of the professor. Measurements of different magnitudes are performed and their relationships analysed through theoretical concepts also learned in theoretical physics courses. In addition to addressing contents related to Physics, measurement techniques, construction and analysis of graphs, evaluation and propagation of uncertainties and errors, simple statistical analysis, among other topics related to experimental activities are also covered.

The laboratories hold a small number of students per class (maximum 24 students), who are divided into groups of a maximum of three members, to carry out the experiment related to the content of the class, obtain their own data and make the respective analyses. This pedagogical dynamic promotes interaction between professor-groups, intergroups and intragroups, since much of the learning takes place in moments of discussion, cooperation and critical analysis, both of the data collected and the results obtained. Professors also sought different approaches and methodologies to enable students to learn the subject's contents. Each experiment has its particularities, usually related to the complexity of execution and the need for specific equipment, which are often not found in the students' daily lives.

In Experimental Physics I, the experiments cover contents of Mechanics, Fluids, Oscillations, Mechanical Waves and Thermodynamics. Such themes allow the search for ways to experience physical phenomena through experimentation outside the university environment, without the need to use specific equipment, using everyday materials and simple and safe procedures. Thus, a proposal was developed based on the 'hands on' experimental physics courses [11], in which the student must carry out the experiments following the guidelines of the professors of the discipline, collect their own data and analyse the results in the light of the concepts physical issues discussed in the support materials. Considering the diversity of different social class of the participants, we tried to develop the experiments so that they could be carried out with materials commonly found in their homes (figures 1(A), (B), 2(A) and 3(A)), avoiding the need to purchase any extra product for specific use in the discipline.

In the remote form, this course, which was taught from May to August 2021, in 12 weeks, had 509 students enrolled. The comparison of the results obtained in this study with the results presented by the previous classes in person allowed the coordinators in the different faculties to evaluate the methodological effectiveness of teaching remotely. At the end of the semester, we extract information related to all the platforms used in the course. In addition, we carried out a poll to find out the students' opinion through a questionnaire, answered voluntarily. The collected results were significant and contributed to the statistical evaluation.

The proposal for the content of the Experimental Physics I course in remote form was divided into two blocks: theoretical and experimental. The theoretical block consisted of three academic weeks, in which the following topics are covered: construction and analysis of graphs, straight line adjustment by the method of least squares, linearization of graphs, measurements and uncertainties and error propagation. This content is also taught in the face-to-face course and provides the tools for data analysis in experiments. During remote teaching, these topics were transmitted to students through recorded classes, synchronous meetings and asynchronous activities carried out in the virtual learning environment Moodle. At the end of this theoretical block, in week 4, an assessment with questions via Moodle was applied: 'Exam 1'.

This course, in face-to-face form, covered eight experiments, one per week. On the other hand, in the DL format, the experimental block lasted 8 weeks, consisting of four experiments with 2 weeks each. The decrease in the number of experiments and the increase in their period was decided by the professors, based on the fact that the students carried out the experiments without the presence guidance of a supervisor (professor or monitors), without specific equipment, only with the materials available in their homes. However, the experiments were chosen in such a way that they covered the same analysis methodologies used in the experiments, in the face-to-face regime. The experiments addressed were: 'Free Fall' (weeks 5 and 6), 'Parabolic Movement' (weeks 7 and 8), 'Springs' (weeks 9 and 10) and 'Simple Pendulum' (weeks 11 and 12). Table 1 shows the distribution of activities per week of the course.

In general, on the virtual learning environment Moodle page, each experiment has two labels: 'Study Room' and 'Hands on'. Within the 'Study Room' label, you will find teaching material, video classes, support and study materials, recommended bibliography, supplementary material (links to the experiment on YouTube, tutorials) and instructions for the experiment. Moreover, within the 'Hands on' label, the student has access to exercises and tasks to be solved online and the possibility of uploading the report regarding the experiment.

Specifically, in the first two experiments, part of the data collection was performed using the free software Tracker [12], with the aid of a cell phone to record the experiment and/or a computer for data analysis. In the last two experiments, the proposal involved less technological resources and could be done using only rulers and timers. In all experiments, the use of everyday objects was suggested, such as lemon (round fruit), bunch of keys, notebook spiral, among others.

3. Experiments description

3.1. Free fall experiment

The 'Free Fall' experiment was divided into two parts: (a) the two objects falling times were measured seven times each; a statistical analysis of uncertainties was performed and the

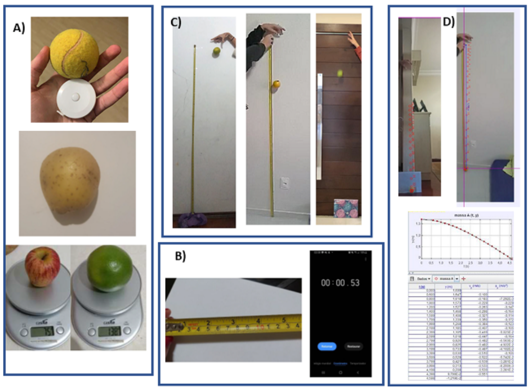

Figure 1. (A) Materials commonly found at home like tennis ball, potato, apple, orange, (B) measuring tape and timer from the cell phone, (C) setup of the experiment, (D) analysis of the experiment using Tracker.

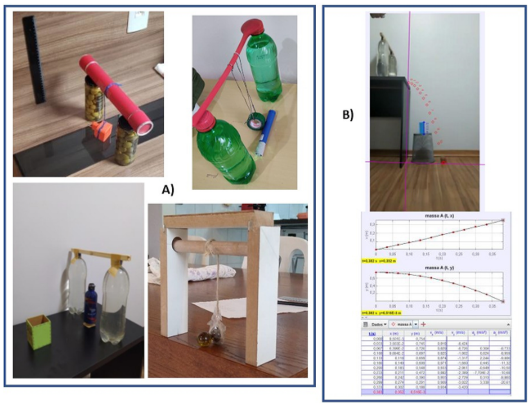

Figure 2. (A) Materials commonly found at home to build a launching system, (B) setup and analysis of the experiment using Tracker.

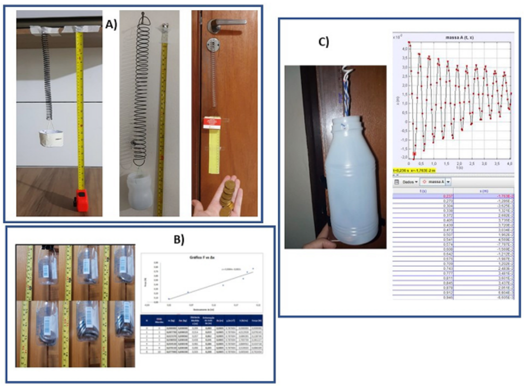

Figure 3. (A) Materials commonly found at home to build a spring experiment, (B) static mode setup and analysis, (C) dynamics mode setup and analysis using Tracker.

local gravitational acceleration was estimated as observed in figure 1(C); (b) the free fall movement was recorded with a digital camera (from the cell phone, for example); the video was transferred to a computer and, using the free software Tracker, a table of position as a function of time was obtained, allowing the estimation of the local gravitational acceleration from a graphical analysis (figure 1(D)).

3.2. *Parabolic movement experiment*

The 'Parabolic Movement' experiment was conducted in a similar way to the Free Fall experiment. However, the aim was to determine the initial velocity of the object launched horizontally from a surface. In this experiment, the student needed to build a launching system (figure 2(A)) that would give the same speed to each launch. The parabolic movement was also recorded with a digital camera and the procedure to analyse the data was similar to the Free Fall experiment (figure 2(B)).

3.3. *Springs experiment*

The 'Springs' experiment was divided into two parts, both with the objective of determining the homemade spring constant (it was suggested to use a notebook spiral): (a) static mode: different 'standard' objects of known mass (for example: 1 real coins whose mass is determined by the Brazilian Mint) were suspended; the spring deformation was measured (figure 3(B)); (b) dynamics mode: the spring mass system was set to oscillate, measuring the period of oscillation, for different suspended masses (figure 3(C)). In both cases, a graphical analysis was performed to determine the spring constant.

3.4. *Simple pendulum experiment*

The 'Simple Pendulum' experiment was divided into two parts: (a) assembly of a simple pendulum (it was suggested to tie a bunch of keys to a string, then tie the string to a support on the ceiling or on the door frame) and measure the period of

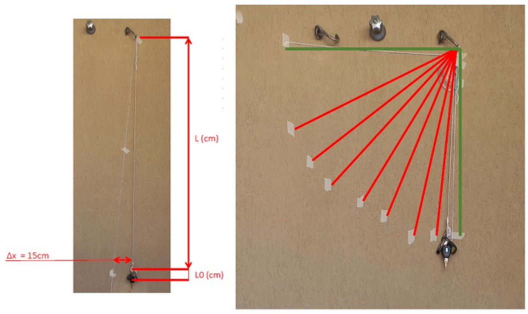

Figure 4. Assembly of a simple pendulum to measure (left) the period of oscillation for small amplitude ($<10°$) and (right) the period of oscillation from 10° to 70°.

oscillation for small amplitudes ($<10°$) varying the length of the pendulum; (b) varying the initial angle of the pendulum by measuring the period of oscillation (from 10° to 70°). In both cases (figure 4), a graphical analysis was performed and the objective was to determine the local gravitational acceleration.

The instructions for the experiments (both execution and data analysis) were given from scripts, recorded classes and synchronous meetings. As a preparation activity for carrying out the experiments, questionnaires called 'Study Scripts' were produced, covering part of the physical concepts involved. The first activity recommended to be performed before each experiment was the Study Guide. At the end of each experiment, the students performed the 'Verification Questionnaires' to check whether the skills related to the analysis procedures of each experiment were achieved. These questionnaires accounted for attendances and grades. Additionally, attendances and grades were also accounted for a 'storyboard' and a 'mini-report' (data analysis and a discussion of the results were required) produced by the student, demonstrating the execution of the experiment/collection and analysis of the physical phenomenon. Thus, we sought to encourage students to have weekly access to the course, allowing the form of assessment to be closer to a continuous assessment. At the end, the students were given the opportunity to make comments/suggestions/criticisms about the way the discipline was organized.

Table 1. Distribution of activities performed per week.

Week	Activities
Week 01	Making of graphics
Week 02	Linearization of graphics
Week 03	Measurements and uncertainties
Week 04	Exam 1
Week 05	Experiment 1: free fall
Week 06	Experiment 1: free fall
Week 07	Experiment 2: parabolic movement
Week 08	Experiment 2: parabolic movement
Week 09	Experiment 3: springs
Week 10	Experiment 3: springs
Week 11	Experiment 4: simple pendulum
Week 12	Experiment 4: simple pendulum
Week 13	Study's week
Week 14	Final exam

4. Video classes and student assistance

The video classes cover theoretical content information that underpins the experiment, as well as execution and analysis details. The preview of video lessons as a pedagogical practice engages with the active teaching methodology. Consequently, the student assumes the leading role in the learning process. The student has the option of choosing the most convenient moment to watch them, establishing their own rhythm during the visualization, repeating them as many times as necessary and taking notes. The video classes are concise (20–30 min on average), containing the fundamental concepts of the experiments and explanation of their assembly. In all, seven video classes were produced covering the seven modules of the discipline (table 1). This distribution corresponded to a workload corresponding to one video lesson per week, plus one week of assistance to answer questions and interact with students.

During the 12 weeks of the course, there was a weekly contact between the professor and the class using a virtual room in the virtual learning environment Moodle platform environment. The virtual room was accessed to the 'E-Class RNP' link. In these virtual meetings, students were able to ask questions about the questionnaires and present the difficulties/doubts they had to carry out the activities. As the resolution, which controlled remote teaching activities in the emergency regime, prevented the charge for frequency in synchronous activities, the presence of students was spontaneous. In addition, in some classes there were monitors, of which students could get in touch to clarify doubts and ask for some help/tip, at alternative times.

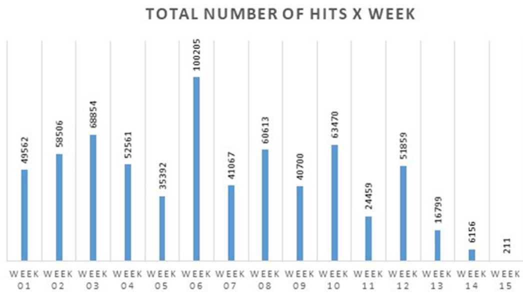

Figure 5. Number of Hits for the 17 classes per week.

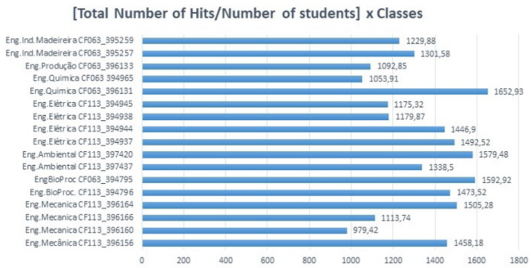

Figure 6. Hits number of the students per course.

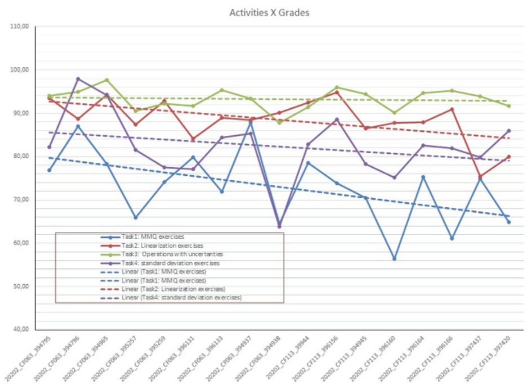

Figure 7. Theoretical activities versus average grades of the class per engineering courses. Idem para o nome das turmas.

5. Results

Figure 5 shows the total number of accesses (17 classes) within the discipline platform per week. We observed that the number of hits per page per week is directly linked to the activities undertaken by the students. There is a greater engagement of students in the sixth week of class, leading to 100 205 Hits, when tasks, scripts, storyboards and reports related to the first experiment were delivered. At the beginning, as expected, there was a greater search for information about the organization of the course, such as 'Presentation' (Presentation Handout—information on schedule, attendance and evaluation). In the first 4 weeks involving access to Lectures 1–3 plus Exam 1, there was an average of 57 370 Hits for the 17 classes. It was observed that the number of Hits in all experiments is lower in the first week (weeks 5, 7, 9 and 11) than in the second week (weeks 6, 8, 10 and 12), when the students deliver the reports/ storyboards and solve the tasks/ questionnaires online. It was noted that the first experimental module 'Fall Free' was the most accessed during the course (weeks 5 and 6), while the last experimental module 'Pendulum' was the least accessed (weeks 11 and 12). We believe that there are two reasons for this result: (i) the experimental module 'Pendulum' demanded more from the student, (ii) students who had already obtained a grade to pass the course directly chose not to access (Hits) the last module.

Figure 6 shows the number of accesses per student (normalized by the number of students) per class. It is possible to observe that the EngenhariaMecanica CF113_396160 class had the lowest number of accesses. On the other hand, the Chemical Engineering classCF063_396131 presented the highest number of accesses.

Figure 7 displays the average of theoretical task grades by class by activities. We can verify that, in all classes, the behaviour of the grade averages related to the theoretical activities varies as follows: Task3 > Task2 > Task4 > Task1, as shown by the dashed lines of the eye guide. These results indicate that task 1 (most difficult and laborious among the others) has the worst trend line. On the other hand, task 3 (simplest activity) presented a trend line with the best scores. Thus, it is possible to conclude that the general behaviour of the classes in the theoretical part was basically similar.

Table 2. Grade averages per course.

Code	Grade averages (Task1 + Task2 + Task3 + Task4)/4
Class 1	92,16
Class 2	91,13
Class 3	88,74
Class 4	88,28
Class 5	86,66
Class 6	86,31
Class 7	85,13
Class 8	85,13
Class 9	84,19
Class 10	83,21
Class 11	82,41
Class 12	82,28
Class 13	81,32
Class 14	81,01
Class 15	80,63
Class 16	77,32
Class 17	76,54

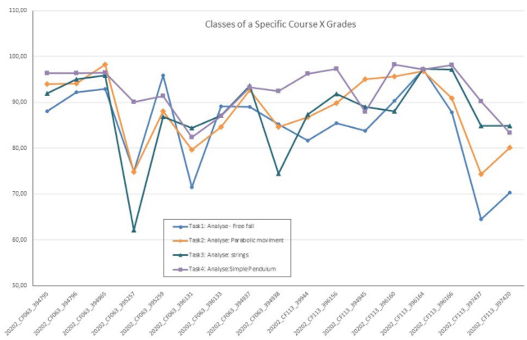

Figure 8. Experimental activities versus grade average of the class per engineering courses.

Table 2 exhibit the average of all assignments per class. In despite of the remote teaching mode, we observe that students managed to obtain grades above the average required by the university (grade = 70).

Figure 8 shows the average scores of experimental tasks by class by activities. We observed three types of behaviour for the experiments: (i) the experiments that presented the greatest variation (approximately 60–100), were: Strings and Free fall, (ii) experiment that presented variation between approximately 70–100, parabolic movements, (iii) experiment that showed variation between approximately 80–100: simple pendulum. In this way, 65% of the classes present similar performance for all experiments, showing a difference between the highest and lowest scores, less than 10.

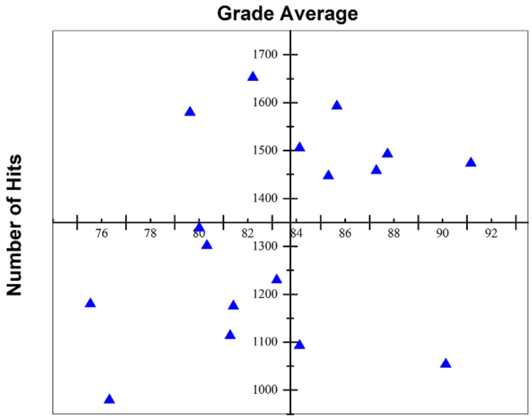

Figure 9. Number of Hits versus grade average.

Figure 9 shows Hits number versus grade average of the classes. We observed that the most engaged classes (access above 1350), presented in the first quadrant in the course had grade average above 84, showing a direct correlation between the number of hits and the grade average of the class. Likewise, we observed in quadrant 3 that the lower number of Hits is related to the lower grade average (lower than 84).

6. Conclusion

The spread of emerging infectious diseases such as Covid-19 is significantly dependent on in-person human interaction activities. We are still dealing with the disease and it is a challenge to predict when it will completely end. However, it is possible to face this problem by reducing the risk of its transmission by changing human behaviour. Therefore, remote teaching can be seen as an option in emergency times as a pandemic, to overcome the impossibility of in-person teaching and the results presented in this study, confirm this trend. The stigma regarding the remote teaching model, related to lack of knowledge, lack of experimentation and resistance to innovation, has been minimized by the pandemic.

The students were encouraged to use more imagination and creativity to carry out the experiments, without the direct intervention of the professor or possible monitors, and without the technical support of a laboratory.

One of the major disadvantages during remote classes was the verification, by the teachers, of the diagnosis on the students' degree of understanding, in most cases, being impractical. This model contrasts with the traditional version of the in-person lecture, where it is possible to perceive relevant questions about the understanding of the exposed subject.

However, the use of weekly evaluations involving the resolution of tasks and online questionnaires and the delivery of mini-reports related to the experiments, as well as the documentation of the assembly and execution of the experiment (through storyboards) and contact through emails and videoconferences, allowed minimize the disadvantage inflicted by the absence of in-person interaction.

In this study we verified: (1) that the choice of the best technologies as a tool for teaching is fundamental for the better dissemination of knowledge, (2) that inclusive programs for each course are very important, (3) the importance of prior presentation of a schedule, (4) the importance of defining clear assessment rules for students, ratifying the recommendations published by UNESCO [13] on remote teaching.

We are aware of the contribution of this article to the discussion of the topic of remote education concerning the learning of experimental physics. With the return of in-person classes, much of the teaching material developed for the remote regime is being used so that this type of evaluation can further improve the quality of the course.

Data availability statement

No new data were created or analysed in this study.

Acknowledgments

We are grateful to Professor Celso de Araújo Duarte for his solidarity and kindness in exchanging information about the Experimental Physics I classes in which he taught. We also thank the entire CIPEAD-UFPR team that made UFPR VIRTUAL available to the academic community and also for their support and professors Paulo Justiniano Ribeiro Junior and Fernando de Pol Mayer from the UFPR Department of Statistics for sharing their knowledge about R-exams.

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Received 9 January 2023, in final form 30 January 2023
Accepted for publication 24 February 2023
https://doi.org/10.1088/1361-6552/acbf1d

References

[1] (Available at: www.gov.br/inep/pt-br/assuntos/noticias/censo-da-educacaosuperior/ensino-a-distancia-se-confirma-como-tendencia)
[2] (Available at: http://abed.org.br/arquivos/CENSO_DIGITAL_EAD_2018_PORTUGUES.pdf)
[3] Theobald E J *et al* 2020 *Proc. Natl Acad. Sci.* **117** 6476
[4] Bergmann J and Sams A 2014 *Comput. Sci. Eng.* **17** 26
[5] Mazur E 1997 *Peer Instruction: A User's Manual* (Hoboken, NJ: Prentice Hall, Inc.)
[6] Mazur E 2015 *Principles & Practice of Physics* (Pearson Education, Inc.)
[7] Zhang P, Ding L and Mazur E 2017 *Phys. Rev. Phys. Educ. Res.* **113** 010104
[8] Crouch C H and Mazur E 2001 *Am. J. Phys.* **69** 969
[9] Araujo I S and Mazur E 2013 *Cad. Bras. de Ensino de Fis.* **30** 362
[10] Paula B S, Camilla C, Hor-Meyll M and Paiva T 2021 Elaboração e avaliação da disciplina remota de Física 1 na UFRJ durante a pandemia de Covid-19 em 2020 *Rev. Bras. de Ensino de Fis.* **43** e20200518
[11] Colóquios do IF UFRJ: cursos de física experimental mão-na-massa durante a Covid-19—UFRJ (available at: www.youtube.com/watch?v=RZBklt-Dj2E), (Accessed 14 September 2021)
[12] (Available at: https://physlets.org/tracker/)
[13] (Available at: www.unesco.org/en/covid-19/education-response)