Perceptions of Mechanical Engineering Students Regarding Flipped Laboratory Activities

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Abstract. Learning in the laboratory is essential in engineering education, but the massification of higher education makes it difficult. Educational technology has opened new possibilities and current trends comprise active methodologies supported by information communication technology, like the flipped pedagogical model. In a mechanical engineering programme in Portugal, curricular changes eliminated all laboratory classes on fluids and heat. To address the need for a hands-on component, optional flipped laboratory activities in thermodynamics were made available to the students. Because these activities require specific resources, like procedures without which they cannot be carried out, this action research aims to evaluate the feasibility of using the flipped approach for their implementation and to identify the type of resources that students perceive as most useful. Thirty-one students attended the activities, which proved to be feasible and which they perceived as contributing to their learning, despite interest being low, and decreasing throughout the semester. The evaluation by the students at the end of each laboratory session proved to be appropriate to the action research methodology. As for the resources, the written procedure is an essential element for laboratory activities and video is a good complement, but it does not replace it.

Keywords: Higher Education · Engineering Education · Flipped Teaching · Laboratory Practice

1 Introduction

The importance of instructional laboratories in engineering education (EE) has been argued by several authors [1, 2]. However, the massification of higher education (HE) requires additional resources. This makes the use of instructional laboratories difficult [3, 4]. On the other hand, the development of information and communication technologies (ICT) has given rise to alternatives [3, 4]. These alternatives can make the use of

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instructional laboratories more efficient [2]. According to the authors [2], some examples include learning management systems (LMS) and mobile technology. At the same time, current trends in EE have favoured student-centred learning methods. These comprise active methodologies supported by ICT, such as flipped teaching and learning [5]. ICT can help HE institutions to reduce costs and allow students to "participate actively and independently in their learning" [6].

In a mechanical engineering programme in Portugal, changes in the curriculum reduced teaching, eliminating all laboratory classes on fluids and heat. Because of the role of experimentation in learning theoretical concepts, some teachers have proposed extra-class laboratory work. However, due to the high number of students, it is difficult to make it mandatory. Furthermore, many students come unprepared to the laboratory, consuming valuable time without really learning. Seeking to address the need for a hands-on component, but considering the existing limitations, optional flipped laboratory activities in the curricular unit of thermodynamics were made available to the students. These laboratory activities were organized in five laboratory sessions (LAB-S). The choice of a flipped approach was based on its suitability to EE [7] and its potential to optimize students' time in the laboratory [8].

A systematic review of the flipped approach in EE [7] found that what is usually flipped are lectures. Additionally, many of the problems reported by the students are technical issues related to educational resources [7]. Considering that laboratory activities require specific resources, like procedures, without which they cannot be carried out, this action research aims to evaluate the feasibility of using flipped teaching for the implementation of extra-class laboratory activities in mechanical engineering and to identify the type of resources that students perceive as most useful. By doing so, the expectation is to contribute to the field of flipped learning in EE, which "is still in its infancy" [7] and with only a few studies in engineering [9].

The following chapters present the theoretical framework, and the methodology, including the description of the intervention, the results and its discussion, and the conclusions.

2 The Flipped Approach

The flipped approach is a pedagogical model in which students have access to content individually and online before face-to-face activities [7]. Flipped teaching complements face-to-face, but does not replace it, since it allows the learning of fundamental concepts autonomously, but implies the existence of a face-to-face component for its development and application [10]. It is flexible enough for it to take different active learning formats, connecting well with other methodologies [11] and the use of digital methods [5]; its flexibility is one of the most cited benefits [7]. Its use has been shown to enhance the active involvement of students, a taste for learning, interaction with teachers [12], and intrinsic motivation and self-efficacy [13].

Considering that the flipped model requires face-to-face interaction, combining this interaction with the online and asynchronous can be considered blended learning [14]. Some authors point out that in engineering teaching, online interaction does not eliminate the need for being face-to-face with a teacher, and that this combination promotes more effective learning [15, 16]. According to Gumaelius and Kolmos [5], in EE the "online part consists of a structured preparation, including videos, quizzes, reading or a collaborative activity", thus relying heavily on the educational resources prepared by the teacher. In the case of Sul, Peng, and Kessissoglou [17], the authors resorted to blended learning in mechanical engineering, using pre-recorded videos of laboratory activities for students to view and analyse before performing them in the laboratory, which is a common practice in flipped teaching [18]. Learning was enhanced with additional information, as "students were required to watch a video recording of the laboratory task which described the instrumentation, safety hazards, procedure, learning outcomes, and reporting requirements" [17]. According to this study, this methodology had many benefits, particularly in terms of saving time and increasing the involvement and commitment of students.

Pre-laboratory preparation can have beneficial effects on reducing students' anxiety and increasing their self-confidence when implementing practice in the laboratory [19]. These benefits can lead to more meaningful learning. Compared to written instructions, using pre-recorded videos of the work can help students deal with equipment, materials, and even better orient themselves in the space and constraints of the lab [17, 19]. Another advantage is that students need less time to complete laboratory work in person and demonstrate more handling skills [19, 20]. Even though videos are the most used resource in the flipped approach [9], using them has some problems, with several authors reporting that students can find online videos boring and that long videos can contribute to students losing interest [7]. According to Aronne et al. [19], in addition to making videos and instructions available to obtain the desired learning benefits, it is necessary to encourage students to take an active attitude towards viewing videos, for example by taking notes or using questionnaires.

3 Methodology

3.1 Participants, Instruments, and Methods

In 2021/2022, 258 students were enrolled in thermodynamics. Of these, 76.3% (197 students) attended classes and were assessed. Thirty-one students participated in at least one of the five LAB-S. This represented 15.7% of those who attended the curricular unit. After attending each LAB-S, the students had to fill in an online questionnaire. The questionnaire was prepared for this purpose and had two sections. The first section was for students to report the measurements and calculated values. The extent and the questions of this section varied according to the theme of each LAB-S. In the second and final section of the questionnaire, they were asked to assess the LAB-S. This section had seven items on a Likert scale from 1 to 5 (strongly disagree, disagree, undecided, agree, and strongly agree, respectively). The items assessed students' perceptions of: 1) the laboratory activities; 2) the resources and technical support; and 3) future intentions. Regarding the laboratory activities, they were asked about their learning. Regarding the resources, they were asked about their adequacy and whether they liked having specific resources and features. As for the support from the laboratory technician, they were asked about its adequacy. Finally, they were asked about their intention to enrol in the next LAB-S and their interest in having this type of activity in other curricular units. This questionnaire was not anonymous.

The educational resources for each LAB-S were made available in an LMS (Moodle). Only students enrolled in a particular LAB-S had access to its resources. Because of that, it was possible to quantify the frequency of their use by the students. This data was thus collected to complement students' answers to the questionnaire. In the case of the video resources, students could access them through links in Moodle, but the videos themselves were on YouTube. These videos were not listed and could only be accessed using the links in Moodle. Because of this, video statistics were available and were also collected.

In this research, the researcher was also the teacher. The teacher intended to address a particular issue and obtain a solution to a problem (the lack of a hands-on component in thermodynamics). To do so, the teacher conceived and implemented an intervention based on theory. A cyclical or spiral process was used, alternating between action and critical reflection. Because of that, this research is action research [21]. Each one of the five LAB-S was a cycle (see Fig. 1). Each cycle included: 1) conceiving and planning the laboratory activities for a particular LAB-S; 2) creating and compiling its educational resources; 3) implementing the LAB-S for the students; 4) collecting and analysing student feedback and the laboratory technician feedback and giving feedback to students. This allowed the teacher/researcher to reflect on her practice. In this way, the results of the research from one cycle (LAB-S) were used to adjust the action in the next cycle (next LAB-S).

3.2 Description of the Intervention

In the scope of the action research that guided this study, an intervention (schematically shown in Fig. 1) was conceived and implemented in the thermodynamics curricular unit of the mechanical engineering programme, between October 2021 and January 2022 (1st semester of 2021/2022).

This intervention consisted of five optional LAB-S, which were available for students. The LAB-S had no weight in the final grade. The themes of the LAB-S were as follow: LAB1 – Temperature measurement; LAB2 – Measurement of pressure and gas laws; LAB3 – Measurement of density; LAB4 – Water phase change; LAB5 – Properties of moist air. The teacher chose the themes considering the available laboratory resources and the content of the curricular unit. Each LAB-S had several laboratory activities (see Fig. 2 for some examples). The five LAB-S had a total of 12 laboratory activities.

The announcement of the activities was made weekly by the teacher in the theoretical classes. The students registered online in groups of two, choosing from one of the time slots available. It was conservatively estimated that each LAB-S would last one hour. Because each session included several activities, two groups of students could be in the laboratory simultaneously, turning over between activities. Each LAB-S was available in the laboratory for two weeks, making up a total of ten of the fifteen weeks of the semester (see the planning in Fig. 3). The planning was done so that up to 40 students could go to the laboratory per week. This planning would ensure that each student could attend at least one to two LAB-S if the demand were high.

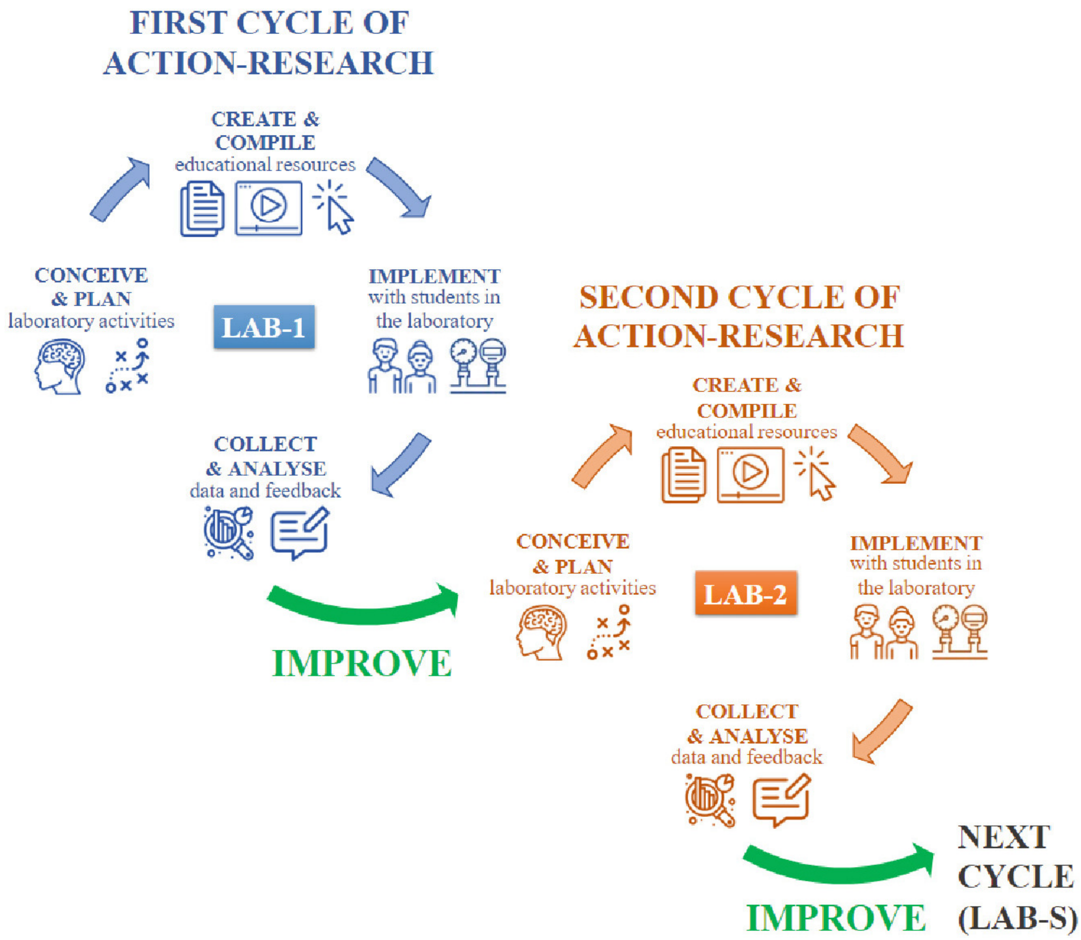

Fig. 1. The cyclical process of action research applied to LAB-S (this scheme was designed using resources from Flaticon.com).

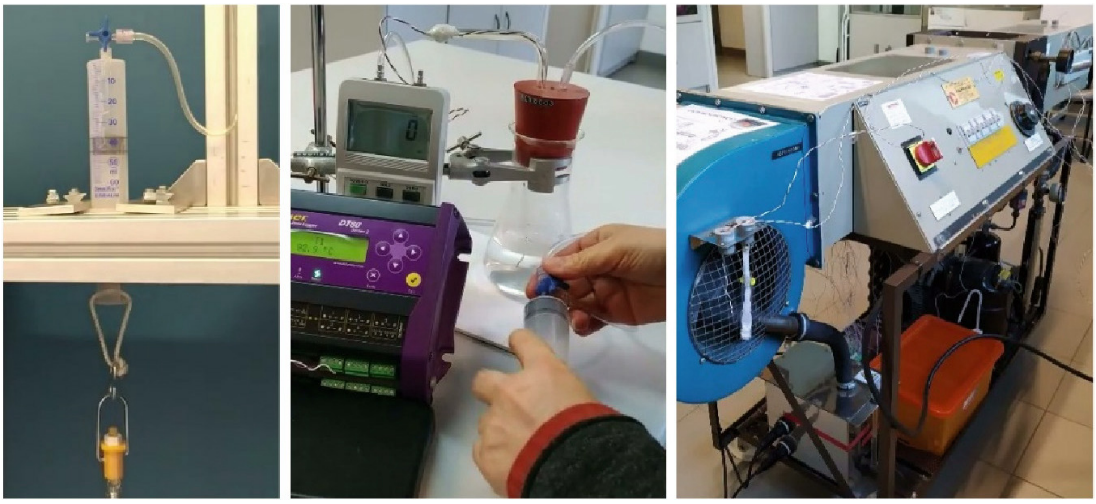

Fig. 2. Examples of three activities in the laboratory (from LAB2, LAB4, and LAB5).

According to the flipped pedagogical practice that framed this intervention, the teacher created and compiled several educational resources. These resources were made previously available on Moodle, but only to students enrolled in LAB-S. In this way,

	OCTOBER 2021				NOVEMBER 2021					DECEMBER 2021				JANUARY 2022				
CLASSES	1	2	3	4	5	6	7	8	9	10	11	12		13	14	15		
LAB-S		1		2				3		4					5			

Fig. 3. Thermodynamic classes and LAB-S planning from October 2021 to January 2022.

they would be able to prepare for the laboratory activities in advance. These resources included: interactive videos of laboratory activities; links to online sites on instruments and measurement procedures and the LAB-S theme; written versions of the measurement procedures; video versions of the measurement procedures; and technical data sheets of all instrumentation and property tables and diagrams.

Nine interactive videos (prepared with h5p in Moodle) that presented the laboratory procedures were made available. There were several types of interactions in the videos, with the possibility of checking that the required answers were correct and retrying and/or continuing. These videos had an average duration of 56 s, with the longest being about two minutes. The footage was made by the teacher in the laboratory in 2020 and later edited (with Moviemaker and/or with the free version of VSDC). The audio was removed, opting for the placement of text captions whenever what was being shown was not sufficiently enlightening.

In the case of the links (twenty in total), sites of instruments manufacturers and others were searched, with information on: various types of instruments in addition to those that were going to be used in the laboratory; selection criteria of one or another type of instruments; and its main characteristics, principles of operation and measurement. The teacher also provided links to videos that demonstrated the use of these instruments in different circumstances and other similar laboratory procedures. The intention was to give students additional variety that could assist them in understanding the concepts involved.

The written version of the laboratory procedures included the experimental procedure itself, the calculations which had to be done, an example of measurements and results, and the list of laboratory materials. Initially, the teacher thought that the video procedure would be sufficient [22]. However, in LAB1 and LAB2, students' feedback indicated they missed the written procedure. This need expressed by the students was considered relevant by the teacher, as several authors that compared written and video instructions conclude that both are effective [23, 24]. Benefiting from the cyclical process of the action research, the teacher made some adjustments and provided the video and written procedures in LAB3, LAB4, and LAB5. Reflecting on students' feedback on this issue, the teacher concluded that the best option was to provide both versions. The written procedure had the advantage of being explicit and allowing an immediate view and access to all its steps. Nevertheless, the video procedure, which showed how to do it, was very useful for the correct positioning of the instrumentation and its operation, complementing and clarifying the written version.

The videos of the procedures were filmed in the same conditions in which the students were going to perform them, in the week preceding each of the LAB-S. They were a faithful reproduction of what students would do in the laboratory, both in terms of the procedure, the material, and the results. In total, fourteen videos were made with an average duration of one minute and eight seconds, with the shortest being eight seconds long and the longest about four minutes.

Of all the instrumentation, excerpts of the technical data were made available in electronic format; when necessary, tables and diagrams with properties were provided in electronic format. There were paper versions of this documentation in the laboratory.

Even though activities were done with students in groups, each student was asked to perform at least one set of measurements and calculations. Also, the teacher asked each student to fill in the questionnaire of each LAB-S.

Finally, recognizing that feedback is an essential element of learning in HE [25], the teacher downloaded all students' answers to the questionnaires to a spreadsheet (through Moodle). Then the teacher added her set of measurements and grouped them into tables and graphs. The teacher made a succinct report with these tables and graphs. She pointed out measurements and results that did not seem correct, commenting on the reasons that might explain it. An analysis of errors and uncertainties was included to help students to understand the difference between procedures and instrumentation. The final part of the teacher's report was the average evaluation of the LAB-S done by the students. The teacher made one report per LAB-S, which included information based on the values reported by all students. In this way, students could learn from what their classmates had done. Initially (LAB1 and LAB2), this report was presented and explained by videoconference, because it allowed immediate clarification of students' doubts. However, it was always very difficult to find a schedule at which all students could attend. Because of that, in LAB3, LAB4, and LAB5, the report was sent to the students by email. The teacher indicated her availability to clarify any doubts that may persist.

4 Presentation and Discussion of Results

The attendance of the LAB-S (see Table 1) was almost the same in the first two (36.5% in LAB1 and 33.3% in LAB2) and decreased from then on (17.5% in LAB3 and 9.5% in LAB4) and was residual in the last LAB-S (3.2% in LAB5). Those who attended only one LAB-S did so in LAB1 or LAB2, and those who attended two did so in LAB1 and LAB2. Those who attended three LAB-S did so mainly in LAB1, LAB2, and LAB3. There was a total of sixty-two enrolments, which means that the average attendance per student was two LAB-S.

As shown in Table 2, most of the thirty-one students (54.8%) who performed the laboratory activities attended only one of the LAB-S, 19.4% attended three LAB-S, 12.9% four LAB-S, and 9.7% two LAB-S. Only one student (3.2%) attended all LAB-S.

Table 1. Number of students attending each LAB-S

STUDENTS	LAB1	LAB2	LAB3	LAB4	LAB5
Absolute frequency	23	21	11	6	2
Relative frequency	36.5%	33.5%	17.5%	9.5%	3.2%

Table 2. Number of LAB-S attended by the students

STUDENTS	1 LAB-S	2 LAB-S	3 LAB-S	4 LAB-S	5 LAB-S
Absolute frequency	17	3	6	4	1
Relative frequency	54.8%	9.7%	19.4%	12.9%	3.2%

To quantify the use of the educational resources, the number of views of the videos of the procedures on YouTube and the average percentage of the duration of these views were collected. As shown in Table 3, it was found that the number of views was in accordance with the number of students who attended the LAB-S, being equal to or higher than the number of students (between 101% and 200%), except in LAB3, which was lower (64%). This can probably be explained by the simplicity of the procedures in LAB3 (LAB3 was the simplest of the proposed themes) and because the written version of the procedure was already available. However, it can also be seen that, even when the written procedures and on topics were quite complex (such as LAB4 and LAB5), the students chose to view the videos. As for the duration of the views (see Table 3), it was practically equal to or greater than the duration of the video (between 95% and 124%), except in LAB3, which was lower (69%).

Table 3. Views and percentage of the duration of the videos per LAB-S

LAB-S	NUMBER OF VIEWS	PERCENTAGE OF DURATION
LAB1	23.3 (for 23 students enrolled)	95%
LAB2	23.5 (for 21 students enrolled)	101%
LAB3	7.6 (for 11 students enrolled)	64%
LAB4	12.0 (for 6 students enrolled)	124%
LAB5	2.0 (for 2 students enrolled)	122%

According to the data collected from Moodle, the interest of the students in the interactive videos was residual. Also, there were little or no interest in links to more information and resources that had not been made by the teacher. The procedures (written and video version) had a level of access equal to or greater than the number of students who attended the LAB-S, corroborating the number of views on YouTube. For example, in LAB4, the number of views was 2.8 times the number of students who attended it. Regarding the technical data sheets and other information, the level of access was also in accordance with the number of students.

As for students' evaluation of the LAB-S, 57 responses were collected out of a possible 62 (91.9%). As shown in Fig. 4, students liked having an example of the results included in the written version of the procedure (M = 4.63, 100% agreeing or strongly agreeing) and having the procedure in writing (M = 4.56, 100% agreeing or strongly agreeing). When the written procedure was not yet available and they were questioned about their preference for this version, they expressed being in favour of it (M = 4.07, 68% agreeing or strongly agreeing). The liking of the video procedure was influenced by the existence of the written version. Students liked the video procedure more after they were given the written version (M = 3.59, 100% agreeing or strongly agreeing and M = 4.69, 100% agreeing or strongly agreeing; without and with the written version, respectively). Almost all students considered having learned (M = 4.47, 96% agreeing or strongly agreeing). They expressed the intention of attending the following LAB-S (M = 4.56, 93% agreeing or strongly agreeing). They would also like this type of activity to be available in other curricular units (M = 4.54, 89% agreeing or strongly agreeing). The support material was considered adequate (M = 4.37, 86% agreeing or strongly agreeing) as well as the support of the laboratory technician (M = 4.21, 84% agreeing or strongly agreeing).

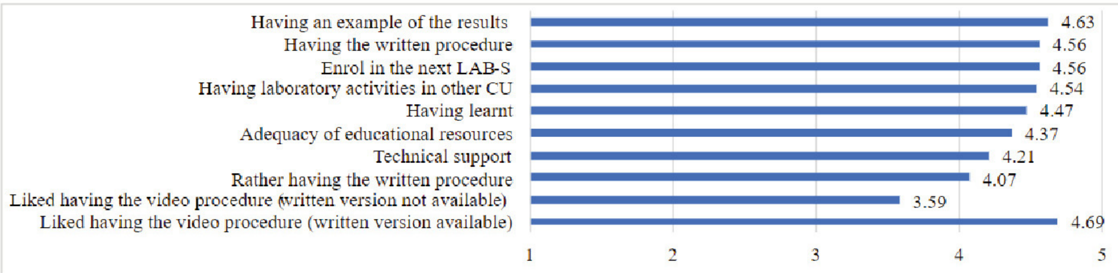

Fig. 4. Students' evaluation of LAB-S (1: strongly disagree to 5: strongly agree).

5 Conclusions

The availability of extra-class laboratory activities in thermodynamics using a flipped approach proved to be feasible, considering the feedback given by the students. Students were able to complete the activities without requiring additional time-consuming explanations. The flipped approach was thus useful to optimize students' time in the laboratory and provide more effective use of the existing resources, as also reported by other authors [8]. Even though there was no assessment involved, since the LAB-S had no weight in students' grades, the results are in line with the effectiveness of flipped learning reported by Karabulut-Ilgu et al. [7], as students perceived the laboratory activities as contributing to their learning.

Despite these positive outcomes, on the negative side, the interest raised was small and decreased throughout the semester. Although students indicated that they would continue to attend LAB-S, their intentions did not translate into action. Considering the general lack of interest, this is more likely to be related to not wanting to do laboratory activities than to the (flipped) approach used. This difficulty in motivating students "to spend more time on experimentation and improve their learning" [2] is well known [26]. Even though there is evidence in the literature that providing students with educational resources to prepare for the laboratory activities in advance promotes engagement [7, 27] and is positively received by the students [22], only students who were already enrolled in LAB-S had access to the educational resources, meaning that these resources did not serve the purpose of motivating students to enrol. As for the LAB-S failing to maintain the interest of students after LAB2, this may be related to the absence of the written procedure making the activities difficult for students. Despite both versions being provided in LAB3, students did not know that before they enrolled. These considerations about students' interest in laboratory activities will not be complete without considering the influence of the pandemic. Because of the restrictions caused by social distancing, these students had half of their classes online, at home. Because of this, they were not at the HE institution on a daily basis, which may have negatively influenced their willingness to spend an additional morning there to engage in face-to-face activities.

The evaluation that students were requested to make at the end of each LAB-S proved to be very important and appropriate to the action research methodology adopted in this study since it allowed some adjustments in the resources made available. However, because the teacher did not inform the students that these improvements were being made, this did not help prevent students from giving up on LAB-S. So, on one hand, the teacher/researcher needs feedback from students on their perceptions, and students need feedback from the teacher regarding the measurements, calculations, and their meaning and relation with content; on the other hand, students need to be aware that they are involved in an action research study and that their feedback will have immediate effect.

Regarding the educational resources, namely the video procedure, the findings only partially uphold the idea supported by the literature that students find it easy to learn from them [27], which is corroborated by statistical data from the number and duration of views [22], as happened in this study. For the students that attended the LAB-S, the written procedure, and not the video, was an essential element for laboratory activities. They considered the video to be a good complement and liked having it, in line with other findings on the importance of videos to enhance students' preparation for laboratory activities [22]. However, for them, the video is not a replacement for the written version, and thus is not as effective. These findings contradict other research that concluded on the effectiveness of both [23, 24], and illustrate the need to provide different types of resources that will accommodate students' needs and preferences.

As a follow-up to these findings, a set of interviews was conducted to better understand the reasoning of the students. These data are still being analysed, but the expectation is that it will allow further improvement of LAB-S, to be implemented in 2022/2023.

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