CHANGES IN THE TEACHING METHODOLOGIES AND ASSESSMENT TO IMPROVE THE ACHIEVEMENT OF THE LABORATORY SKILLS FOR FIRST-YEAR ENGINEERING STUDENTS AT THE UNIVERSITY OF THE BALEARIC ISLANDS

M.A. Jiménez, M.M. Vich, A. Grau, A. Maimó, F. Molinos

University of the Balearic Islands (SPAIN)

Abstract

It is well known that the teaching methodologies and assessment in the laboratory lectures must be carefully designed to guarantee the degree of achievement of instrumental skills, such as data acquisition (presentation, units and associated errors) and their corresponding analysis to compute a physical magnitude. This present work aims to apply the improvements cited above to General Physics, a first-year course of the Degree in Automation and Industrial Electronics Engineering. The teaching strategies and assessment will be changed to improve the achievement of the skills assigned to this course in the official curriculum of the degree. Regarding the methodology, the following three actions have been applied: (1) make the protocol clearer regarding the explanation of the experiment (improve the layout and incorporate short instructional videos); (2) prepare several tasks before the laboratory lessons to make sure that students have understood the goal and methodology of the experiment; (3) strengthen the links between the laboratory and class lectures. For the assessment, these two actions have been implemented: (1) guarantee that students receive feedback of their delivered works; (2) use a public rubric for the assessment.

These actions have been progressively applied during three academic years (2018-19, 2019-20 and 2020-21). To quantify the improvements, the laboratory skills have been revised, comparing students´ deliverable works for the analyzed years and from the answers of an opinion poll. Results show an improvement in the degree of the achievement of the laboratory skills (especially those related to the measurements and their post-processing and presentation of the results). It is important to note that, during the 2020-21 academic year, the organization of laboratory lessons was modified due to the COVID-19 pandemic, impacting current results. In any case, a strong focus remains on students working in pairs in the laboratory, especially to practice and enhance critical thinking and other laboratory skills.

Keywords: laboratory lectures, sciences, engineering, methodology, assessment.

1 INTRODUCTION

Teaching methodologies based on laboratory lectures are often applied in science courses to assess their skills for several reasons [1, 2, 3, 4, 5, 6, 7]: increase interest and motivation of students, improve students' problem-solving abilities, foster dialogue and collaboration amongst students, understand the limits of theories, enhance critical thinking, learn experimental techniques and procedures or understand the importance of security rules, among others. Accordingly, it is crucial to select appropriate experiments to further practice the theoretical concepts. Choosing adequate methodologies and evaluation methods for the laboratory lessons is important to guarantee the assessment of the skills related to the subject [5, 8, 9, 10].

Particularly for engineering degrees, science laboratory activities are a part of the course and theoretical or problems lectures are also considered in curricular assessment. In general, a quarter of the total number of activities of the course are related to laboratory experiments. At the University of the Balearic Islands (UIB), the General Physics course in engineering degrees has 6 ECTS credits (150 hours of total workload distributed in 60 hours of lectures in person and the rest of autonomous work). The laboratory lectures consist of about 15 hours in person (plus about 25 hours of autonomous work), corresponding to 4-7 sessions of 2-3 hours. Students work in pairs and in general the lecturer to student ratio is between 1:10 and 1:15. Assessment of laboratory activities takes into account work completed during (abilities/attitudes) and after (deliverables) the lab session, which correspond to 25% of the final mark.

Lecturers of the Science Faculty at UIB reviewed the laboratory lessons [8] for engineering degrees and the following points were highlighted:

1 It is important: (a) to have an adequate laboratory [11], (b) to properly select the experiments (taking into account the concepts previously reviewed in in theoretical lessons) and (c) sufficient time for each experiment.
2 The instructions and procedures that students must read (known as protocol) before starting the experiment should be clearly presented.
3 A rubric could be very useful for the assessment, especially if students are made aware of it before performing tasks related to the experiments.
4 For the assessment, a deliverable work for each laboratory experiment is better than submitting an extended report of one experiment. A fast feedback is also crucial to avoid repeating the same mistakes along all the experiments.
5 It is important to link the class and laboratory lessons to allow students to have a perception that both activities are designed to assess the skills of the subject [11]. Fix a minimum grade for the laboratory activities avoid students passing the course without assessment of laboratory skills.

The conclusions reached in [8] were applied to Mechanics, a first-year core training course of the Degree in Construction at the UIB, to strengthen students' instrumental skillset [9]. Several actions were performed in the methodology and assessment:

1 Laboratory sessions started after the theoretical and problem-solving lessons (students worked on the theoretical and practical contents in the class lessons).
2 Before starting the laboratory sessions, some activities related to instrumental skills were performed by the students, of which they had to perform various tasks prior to beginning the laboratory sessions.
3 Protocols of all laboratory sessions were reviewed for clarity and transparency so that they may better guide students to perform measurements and corresponding data analyses.
4 During the assessment, feedback was given to avoid repeating the same mistakes.

In quantifying the degree of achievement for the different experimental skills evaluated, a significant improvement was found after applying these actions when compared to the previous academic year, in which the aforementioned actions were not applied [8].

In the current work, the above-mentioned results [8, 9] are applied in General Physics, a first-year core training course of the Degree in Automation and Industrial Electronic Engineering at the UIB. The main objectives are to:

a) guarantee that when students perform the experiment, they have previously understood it (read the information provided in the protocol) and they know the physical magnitudes to be derived from the measurements,
b) check that the protocol is adequate to the skills of the subject,
c) make the assessment a part of the methodology for the achievement of the skills and
d) increase the achievement of the instrumental skills (they are common in other subjects of the degree)

After applying several actions and conducting thorough analysis across three academic years (2018-19, 2019-20, 2020-21), it is agreeable that the final goal is to improve the achievement of laboratory skills through teaching methodology and assessment. Also, the improvements across the three academic years were quantified via comparing the degree of achievement of laboratory skills.

2 METHODOLOGY

The following sections define the analyses conducted in changing the organization of the laboratory lessons (labeled as O), teaching methodologies (M) and assessment (A) to improve the achievement of laboratory skills. The evolution across the three academic years (2018-19, 2029-20, 2020-21) applied to the General Physics course in the Degree in Automation and Industrial Electronic Engineering at UIB are explained. Several actions were applied each academic year, with a summary provided in Table 1. The actions were applied to improve student assimilation of concepts that were previously explained in the classroom. Ultimately, the aim of the applied actions is to strengthen students' laboratory skillset in the course analyzed as well as across the engineering course offerings. Finally, a method is proposed to quantify the impacts of these actions in terms of evaluating the laboratory skills (Table 2) achieved by the students.

2.1 Changes in the Organization of Laboratory Lectures

These changes (labelled as O) are explained here and summarized in Table 1.

O1. Perform laboratory experiments when the corresponding theoretical concepts have been addressed in the class. There are many student cohorts that occupy the laboratory during the semester. This impacts the laboratory schedule and laboratory sessions (they are simultaneously to the theoretical lectures). As pointed out in [8], it is important to avoid doing experiments before the concepts are explained in the class. To prevent this from happening, since the 2019-20 academic year, laboratory sessions are scheduled only after the theory has been addressed in the classroom (this is guaranteed with the exception of some students and the experiment 4). A similar action was performed in [9] and their analysis suggests a positive impact.

O2. Optimization of the duration of the session. It is important to guarantee that students will have enough time to perform the experiments and compute all the parameters requested. Also, it is necessary to adapt the type of the experiment to the skills of the degree [8]. During the 2020-21 academic year all experiments were revised accordingly. For instance, in some cases the number of repeated measurements had been reduced and in others the experiment had been shortened. As a result, students have more time to revise their measurements, compute the physical magnitudes requested, and critically review their results.

O3. Measurements and the corresponding derived physical magnitudes are delivered at the end of the laboratory session. Students have to write down their measurements in empty tables that are given with the laboratory protocol. They often print these pages and complete the tables with the measurement, but they can also put them in the computer and fill them electronically. A few years ago (academic year 2018-19), it became mandatory that all the tables be completed with the corresponding data by the end of the session. Lecturers help students and review with them that everything is consistent. It is important to fill in these tables in order to prepare the deliverables (see section 2.3).

O4. All the deliverables are given in electronic format through a virtual classroom. Students have a virtual classroom with all the materials related to the course (theory, list of problems, practice protocol, etc). Since the 2019-20 academic year, all deliverables in PDF format must be submitted through the virtual room. The system allows students to see the calendar of the deliverables, and this can help them get organized for independent work. Notably, providing deliverables in an electronic format reduces the amount of paper that is printed and enhances feedback (see section 2.3) as the annotations in PDF or tools within the virtual room are clear, transparent, and easy to navigate.

2.2 Changes in the Methodology of Laboratory Lectures

These changes (labelled as M) are explained here and summarized in Table 1.

M1. Improve the protocol and provide videos to complement the information therein. The protocol is a document available for students within the virtual classroom, where descriptions are provided with regard to the objective, methodology, and expected results for each experiment. There is also a description of the data analysis and some questions that should be included in the deliverable works for each experiment. It is important to encourage students to read the protocol before going to the laboratory and it is therefore necessary that the information is clearly presented. Since 2019-20, the protocols of each experiment have been revised and in 2020-21 students have had access to some (short) videos where the experimental setup and procedures for each experiment are explained.

M2. Prepare previous tasks to practice the data analysis of the measurements. Since 2018-19, laboratory lecturers have seen that some of the requested computations/data analysis in the deliverable works were wrong and students often failed due to the same reasons. In response to this, beginning in the 2019-20 academic year, an introductory course for the laboratory sessions were offered and four new previous tasks were designed to support students as they familiarize themselves with the instrumental skills needed for the deliverable works. This action was made previously in [9] where the achievement of the skills was improved. A total of four previous tasks of progressive complexity have been delivered by students in 2020-21 before starting the laboratory sessions. Lecturers have corrected them and given feedback to the students to learn from the mistakes.

M3. Link between the laboratory and class lectures. This is especially important in General Physics in engineering degrees where laboratory sessions are only a part of the subject. Students must recognize the importance of both the class and lab sessions as each are designed in dual part to achieve the skills related to the course. Since 2019-20 experiments to be performed in the lab sessions are first announced during class lectures. During 2020-21 some class lectures were devoted to solving a problem totally linked with each experiment to further explain how a physical magnitude can be computed from observations.

Table 1. Description of the actions that have been taken into account during the last three academic years classified as: organization (O), methodology (M) and assessment (A).

Action	*2018-19*	*2019-20*	*2020-21*
O1. Perform laboratory experiments when the corresponding theoretical concepts have been addressed in the class		x	x
O2. Optimization of the duration of the session			x
O3. Measurements and the corresponding derived physical magnitudes are delivered at the end of the laboratory session	x	x	x
O4. All the deliverables are given in electronic format through a virtual classroom		x	x
M1. Improve protocol and perform videos to complement the information therein		x	x
M2. Prepare tasks beforehand to practice the data analysis of the measurements		x	x
M3. Link between the laboratory and classroom lectures		x	x
A1. Deliverable works for each experiment and feedback		x	x
A2. Use a rubric for the assessment			x
A3. Fix a minimum mark for the laboratory lessons to pass the course		x	x

2.3 Changes in the Assessment of Laboratory Lectures

These changes (labelled as A) are explained here and summarized in Table 1.

A1. Deliverable works for each experiment and feedback. Prior to the 2019-20 academic year, the assessment of laboratory sessions was made through extended reports of one experiment that was assigned to each student by the lecturer. The quality of these reports was very poor (the introduction and methodology were correct, but the analysis of the results and conclusions was very poor). In [8], an assessment was made based on deliverable works for each experiment, which were shorter than the extended report. Afterwards, in [9], conclusions were drawn that the delivered works strengthened students' understanding of the experiment. As of the 2019-20 academic year, deliverable works for each experiment have been required. They have to be delivered about two weeks after the experiment and, immediately afterwards, lecturers correct them and return them to students with feedback to avoid repeating the same mistakes in the next deliverable work. Due to the number of reports to correct, a detailed revision is made for the first delivered work.

A2. Use a rubric for the assessment. For the year 2020-21, a rubric was designed to assess the deliverable works. Students had access to the rubric through the virtual classroom when the laboratory sessions started. The rubric describes the criteria of the grading for the analysis of the deliverable works.

A3. Fix a minimum mark for the laboratory lessons to pass the course. Laboratory sessions used to make up a quarter of the final mark. Theoretically speaking, students were once able to pass the course without completing the work related to the laboratory sessions. To avoid this, a minimum grade for laboratory sessions was fixed in the 2019-20 academic (4 over 10 points) to ensure that students complete the experiments and deliverable works of each laboratory session.

2.4 Evaluation of the Effect of the Actions

In order to evaluate the impact of the actions listed in Table 1, as explained in the previous subsections, the deliverable works for the three academic years were analyzed. For each of the four laboratory experiments—the experiments remained the same for each of the three academic years analyzed—we thoroughly examined if the instrumental skills, defined in Table 2, were achieved by the student cohorts. We quantified our results by percentages of students that conducted which of the four experiments and corresponding skills achieved. Afterwards, an average of these percentages for all experiments was made to check which skill is most improved. This research is conducted every academic year to produce a longitudinal analysis that may be examined in order to look further into student academic achievement within each of the four experiments.

Table 2. Description of instrumental skills analyzed in this work.

Skill	*Description*
1	Adequate presentation of the measurements (tables)
2	Quantify the experimental error of the measurements
3	Derivation of physical magnitudes from observations
4	Express the results with the appropriate significant digits
5	Express the results with an adequate unit system
6	Reasoned discussion of the results
7	Proper use of the graphical representation of the observations/results
8	Make a linear fit of experimental data and find a physical magnitude from the slope of the equation.
9	Calculate the error of derived magnitudes (error propagation)

Special attention is given to the year 2020-21. Due to the COVID restrictions, students have to work individually in the laboratory (not in pairs as in the previous years). Additionally, students only attend 2 of the 4 laboratory sessions (each student did experiment 1 or 2 and 3 or 4, lecturers organize the schedule in this sense), but they have to give in all the deliverable works. For this reason, the protocol and videos (action M1 in Table 1) became quite useful as lecturers were able to provide measurements of each experiment to the students to perform their own data analysis and complete their deliverable works. We measured the achievement of instrumental skills by analyzing groups of students that attended laboratory sessions and those that performed their experiments virtually (that is, those that saw the video and performed the data analysis using the observations provided by the lecturer).

3 RESULTS

3.1 Improvements in the Methodology, Organization and Assessment

Achievement of instrumental skills (listed in Table 2), averaged over the four laboratory experiments, is shown in Figure 1 for each of the three academic years. Degree of achievement of instrumental skills is measured by quantifying the percentage of students that correctly answered questions in the deliverable works. It is important to notice that the assessment for the 2018-19 academic year was conducted differently. It was made due to an extended report, rather than examination of tasks prepared by lecturers prior to experiments and the deliverable works themselves.

As can be seen by the various plots, tables, and charts of the deliverable works, there was significant improvement in the instrumental skills analyzed, especially when comparing the 2020-21 academic year to each of the other academic years analyzed. Further, skills with a high level of achievement are slightly improved or remain constant.

Figure 2 shows that in experiments one and two, it was found that skill 7 (properly present the results) had the most significant change in degree of achievement for students. Whereas, for experiments three and four the most significant improvements of degree of achievement were found related to skills 2 and 4 (quantify the error of the measurements and express the results in correct units, respectively). These differences are due to the type of the experiment, the measurements, and the corresponding data analysis (i.e., each instrumental skill is not equally as relevant for each of the four experiments).

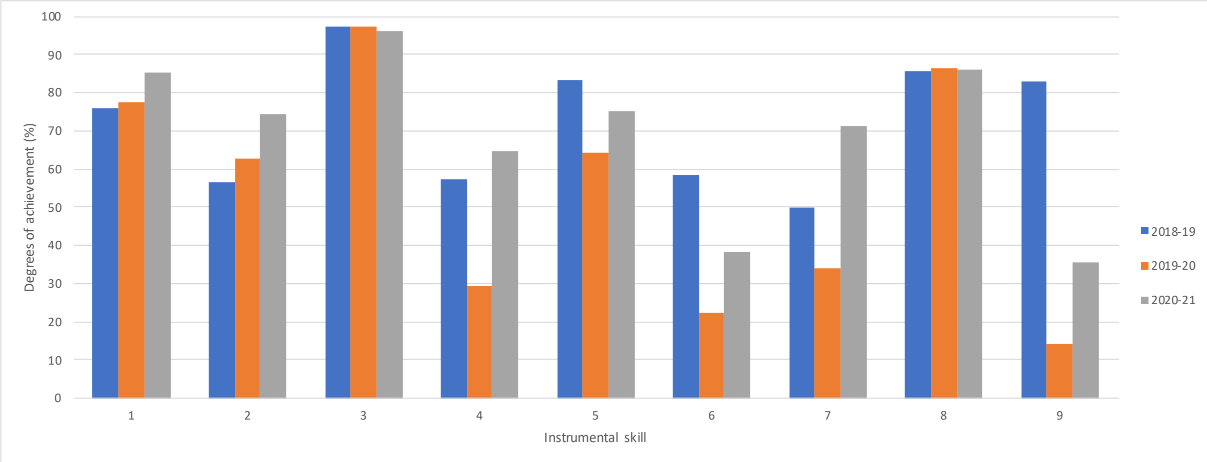

Figure 1. Average of the degrees of achievement for all the laboratory lectures of all the academic years analyzed (represented by a color: in blue for the 2018-19 academic year, in orange for 2019- 20, and in grey for 2020-21) for each instrumental skill studied in this work (see the complete list in Table 2).

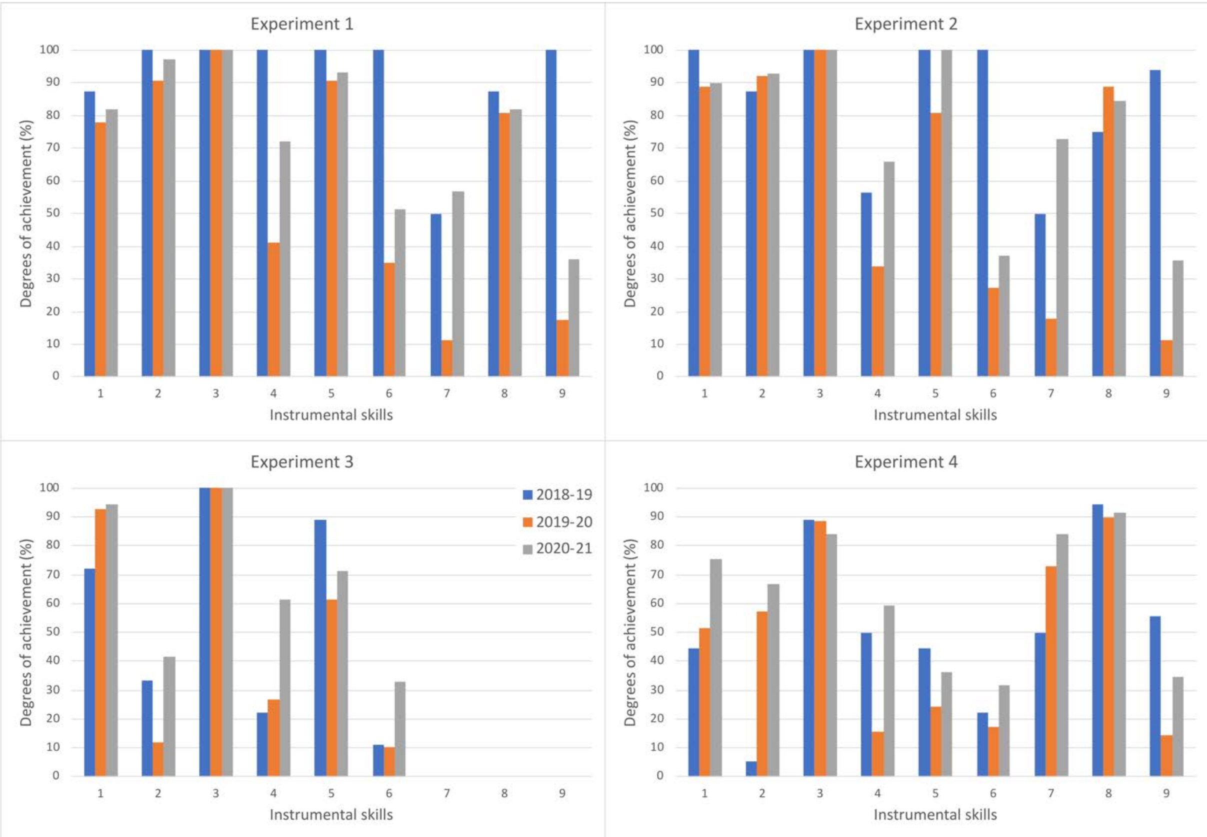

Figure 2. The same as Figure 1 but for the four experiments.

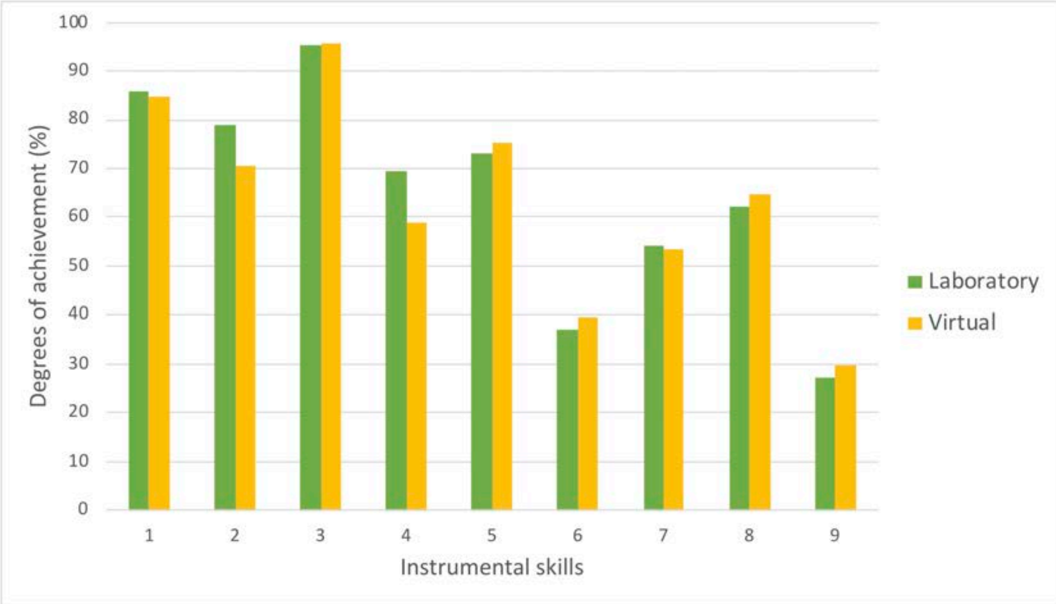

Figure 3. Comparison of the degrees of achievement for the 2020-21 academic year for each instrumental skill studied in this work regarding the presence (green bar) or virtual (yellow bar) classes due to the COVID-19 pandemic.

3.2 The Effect of the COVID-19 Restrictions

For the 2020-21 academic year, the degree of achievement of the skills is evaluated in terms of the class or virtual the laboratory sessions. In Figure 3, the achieved skills for students that did the experiment in class, through independent work rather than paired work, are compared to those achieved for students that did the experiment virtually (reading the protocol, watching the video, and doing the data analysis with the measurements provided by the lecturer).

Inspecting Figure 3, there are not significant differences for the class (performed in the laboratory) and virtual (using the videos and measurements provided by the lecturer) laboratory sessions, but a slight improvement is noticeable when students did the experiments in the laboratory. However, results in Figure 3 might suggest that changes in the protocol and the videos are useful and help students to further understand the experiment and the data analysis included in the deliverable works.

3.3 Student's Perceptions of the Actions

A student opinion poll was conducted during the 2020-21 academic year to further evaluate the impact of the actions and results are shown in Figure 4. The most positive actions were the use of a rubric for the assessment (action A2 in Table 1), the available videos for each experiment (action M2), and the link between the class and laboratory sessions (action M3). The rest of the actions are close to "quite good".

Another significant improvement is that about half of the students prepared a table on their computers before the laboratory session. This preparation allowed students to introduce the measurements during the experiment as well as compute the derived physical magnitudes faster than using a calculator. This fact also shows that they carefully read the protocol and watched the video which was made available for all student cohorts regardless of whether or not they were in person or virtual.

In the open answers of the poll, most of the students mentioned that they prefer to work in pairs in the laboratory to discuss the measurements and critically review the results.

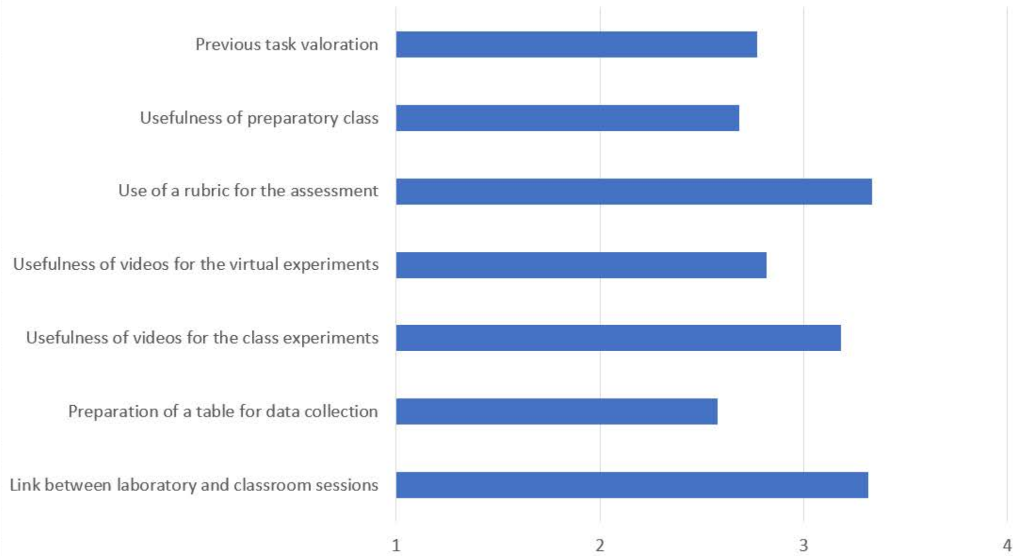

Figure 4. Average student opinion poll (only for 2020-21) results on a scale of 1 to 4, being 1 the lowest rating and 4 the highest (1: extremely unlikely, 2: unlikely, 3: likely and 4: extremely likely). The item "Preparation of a table for data collection" is rated 4 for students who prepared it and 1 for those who didn't.

4 CONCLUSIONS

Several actions have been applied to the laboratory lessons of the General Physics course of the Degree in Automation and Industrial Electronic Engineering at the UIB during the years 2018-19, 2019-20, and 2020-21 to improve the achievement of the skills of the subject (and also those related to the instrumental skills shared with other subjects of the degree). These actions are related to:

1. the organization of the sessions (perform laboratory experiments when the corresponding theoretical concepts have been addressed in class, optimization of the duration of the session, measurements and derived magnitudes are delivered at the end of the session);
2. the methodology (improve the protocol supported by videos, design a task to be given prior to laboratory sessions, link the class and laboratory session);
3. the assessment (deliverable works for each experiment, use a rubric for the assessment, fix a minimum mark for the laboratory lessons to pass the course).

These actions have been progressively applied during the last three years and it is found that in the 2020-21 academic year the degree of achievement of some skills has significantly increased:

- more students express the results with the appropriate significant digits,
- the discussion of the results is now more reasoned,
- improvement in the graphical representation of the observations/results,
- the experimental error and the calculation of the error of derived magnitudes are now more clearly explained.

Apart from the increase in the degree of achievement of these skills, results from a poll suggest that students are in favor of all these actions. They can be easily applied to other laboratory lessons in the same degree or in other engineering studies.

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