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Innovations for laboratory sessions in engineering: Pre-lab H5P videos and reporting results through *ad hoc* applications

Ricardo Castedo[1*], José J. Ortega[1], José M. Gómez[1], Ángel Prado[1], Lina M. López[1], Anastasio P. Santos[1], Marta Fernández-Hernández[1], María Chiquito[1], José E. Ortiz[1], Elisa Costamagna[2]

[1] ETSI Minas y Energía, Universidad Politécnica de Madrid, Madrid, Spain
[2] Department of Environment, Land, and Infrastructure Engineering (DIATI), Politecnico di Torino, Turin, Italy
* Corresponding author: ricardo.castedo@upm.es

Abstract The use of digital tools was introduced in the laboratory teaching of different engineering subjects. Before the laboratory sessions, the students must watch interactive videos created with H5P technology and answer the different questions inserted in them. After the face-to-face sessions, the students must process the experimental data by using applications developed for this purpose in MATLAB, with the aim that students could focus more on learning the concepts and less on the repetitive calculations. The delivery of results by written reports is replaced by encoded Excel files exported from these programs. They also contain some minigames to perform simple simulations related with the work. The overall improvement of the pass rates of the practical exercises with respect to the traditional methodology was around 21% the first year. According to different surveys, the students had a good appreciation of this methodology, rating it higher than 4.3 in a scale up to 5.

Keywords Digitization, Laboratory teaching, Cross-cutting competencies

1 Introduction

The teaching method of many subjects in applied sciences or engineering disciplines usually includes practical sessions where the students carry out in a laboratory different demonstration activities of theoretical concepts taught in the classroom lessons. This is the case, for instance, in chemistry [Teo *et al.*, 2014], physics [Gómez-

Tejedor *et al.*, 2020], or fluid mechanics [Garrard *et al*., 2020; Vaidya, 2021]. However, these well-established practical activities have not evolved much over the last decades, with few innovative elements in the way that students must prepare or realize the laboratory work, or deliver their results. Therefore, the common procedure that they follow consists in reading a guide of the practical session, collecting the requested data in the laboratory, performing the necessary calculations at home, and delivering a report with the results, usually on paper [Gómez-Tejedor *et al.*, 2020].

In recent years, advancements in teaching methodologies like the flipped classroom and problem-based learning, coupled with the emergence of new software and communication technologies, have enabled educators to modernize their approach to practical teaching. Different examples can be found [Gómez-Tejedor *et al.*, 2020; Teo *et al.*, 2014] where laboratory manuals are complemented by explanatory videos that the students must watch before attending to the practical session. In some cases, students also must answer related questions at that stage. With this reinforcement of the previous preparation, the initial explanation given by the teacher can be skipped or substituted by a short session for solving doubts.

A different approach consists in a complete redefinition of the practical activity with the aid of digital technologies like virtual reality (VR). This allows the creation of a "digital twin" of the laboratory in a virtual environment where the student can perform a simulation of the real experiments or physical tasks [Deniz *et al*., 2022; Vaidya, 2021]. This method can be perfectly implemented in the cases where the goal of the proposed experience is just to put into practice theoretical knowledge and not to gain manual skills.

Virtual labs are especially useful in cases that are subject to different limitations such as the low availability of time, physical laboratories, equipment, or resources (like in overcrowded groups), or to alleviate the effects of external factors such as those imposed by the recent COVID-19 pandemic. Thus, virtual or remote laboratories can complement the hands-on activity or even replace it completely [Campari *et al*., 2021; Heradio *et al*., 2016].

Zacharia and Olympiou (2011) made a comparison between virtual and physical laboratories, revealing their equal effectiveness in fostering conceptual understanding. Nevertheless, certain drawbacks emerged, notably the substantial effort needed for developing these laboratories and training students in their proficient utilization [Boettcher and Behr; 2020]. In addition, when laboratory sessions are replaced by these techniques, the practical experience may be impoverished in some regards, due to the incomplete experimental content or the low interaction between peers, as examples [Kapilan *et al*., 2021].

The earlier studies indicate that the new teaching methods in labs mainly focus on two things: the tasks that students complete before the lab session and how the lab session is organized. This might involve partly or completely substituting hands-on work with virtual tasks. However, no work has been found that focuses on the improvement of the classic delivery of results through the traditional reports written by students. During the digital era, and the two years of the pandemic, it is questionable whether the delivery of laboratory reports should still be "analog", with the limitations that this entails.

The present chapter shows the changes that were implemented in the laboratory sessions of two engineering subjects to improve their teaching process. The

evaluation of their effect on the obtained results is based on the comparison with control groups using the previous methodology. The introduced changes mainly comprised the digitization of the pre-laboratory homework, by means of H5P videos with inserted questions, and the post-laboratory data treatment and delivery of results, by using applications developed "*ad hoc*" for this purpose. The core of the learning experience intended by these practical activities in laboratory remained as the face-to-face sessions where the students can handle the equipment with their own hands and can get to a direct contact and understanding of the involved physics.

2 Academic context

The new methodology was applied in two courses taught at the School of Mining and Energy Engineering of the *Universidad Politécnica de Madrid* (Spain): "Heat and Mass Transfer" and "Fluid Mechanics and Hydraulics". Both are included in the Energy Engineering bachelor's degree program (Spanish acronym GIE). The last one also belongs to the initial two-year program common to three bachelor's degrees that branch from it in the third year: B.Sc. in Geological Engineering, B.Sc. in Mining Technology Engineering, and B.Sc. in Energy Resources, Fuel and Explosives Engineering. As a result, we refer to the common program as the multi-degree program (Spanish acronym MG). Both courses are taught in the second semester of the second year and are compulsory. They consist of 6 credits of the European Credit Transfer System (ECTS), so, in total, they have 60 in-person hours available for classroom lessons, laboratory, and mid-term exams.

With respect to laboratory, the subject "Heat and Mass Transfer" has one-hour session where the students measure the thermal conductivity and the difference of temperature in windows with thermal break. This laboratory session was included in the course for the first time in the year 2021–2022, directly applying the innovations presented in this work. The activity was voluntary that first year and compulsory from then on.

The other subject covers from fundamentals of fluid mechanics to engineering applications. Currently, four compulsory practical works are developed in two laboratory sessions of two hours each. This laboratory program was implemented in the academic year 2019–2020, extending the existing one. In the year 2020–2021, the innovations explained in this chapter were also introduced in one of the two student groups of each degree (in GIE and in MG), for comparison purposes. In the following years, the new methodology was applied in every group. The first laboratory session consisted of the study of hydrostatic forces on a vertical submerged surface and the Reynolds experiment, to demonstrate laminar and turbulent flows. The second session consisted of the study of the Bernoulli equation, by using a Venturi flowmeter and piezometer and Pitot tubes, and the determination of the characteristic curves of a centrifugal pump.

3 Methodology

The modifications introduced in the practical sessions address, in the first place, the students' preparation for the laboratory activities and, in the second place, the calculation procedure and the way in which the students report their results. The evaluation of the effect of these innovations on the learning process is based on the numerical results obtained by the students depending on the applied method and on their opinion collected by the corresponding surveys.

In the first case, this was made possible in the subject of fluid mechanics by randomly dividing the students into "experimental" and "control" groups. The experimental groups had access to the new material (videos and applications) and followed the new procedure to pass this part of the course while the control group continued using the classical materials and methods. As introduced before, in "Heat and Mass Transfer" the practical lessons were directly established with the new methodology in all groups.

Oposite to the traditional method [Gómez-Tejedor *et al*., 2020], the new method implemented here is based on the use of digital resources. First, the students are asked to watch a video that explains the corresponding practical exercise, thereby introducing an element of flipped classroom. These videos contain inserted questions that they must answer. The teacher can check what students have completed that step, granting them access to the laboratory session only in that case. There, the development of the in-situ activity is the same that with the traditional method. Finally, the students process the acquired data by using computer applications that have been developed for each exercise. The output of the applications is an Excel file encoded for each student, thus avoiding plagiarism, and this is what they deliver, instead of a written report.

The pre-laboratory videos explain the experimental procedure, the operation of the equipment and the collection of data for each laboratory exercise. They are stored in a YouTube channel and are accessed via the Moodle page of the course. They were developed as short interactive videos using the H5P tool, which allowed the insertion of several questions within the video that prompt at different moments along its duration (see Fig. 1). The students must select an answer to continue and, after completing the video, they confirm their answers to the questions, which are sent to the Moodle platform.

Following the data collection in the laboratory, students analyze their data using dedicated software applications. These applications were developed using the MATLAB programming language, but this could be done in any other language that the reader is comfortable with. MATLAB was selected due to its user-friendly tools for developing such applications. Additionally, it is part of the curriculum in early academic years at the School, which ensures that students are familiar with it.

The design of each application varied depending on the objective of the exercise, but they share certain aspects. In general, they seek to help the students apprehend the theoretical concepts and how to apply them, rather than focusing on numerical calculations, as it is usual in the traditional methodology. The use of applications allows greater flexibility in this regard, as they are more visual and interactive. They

also offer many capabilities for simulating different practical situations related to the topic of the exercise, for example, in the fashion of mini-games, extending in this way the learning scenario beyond the laboratory limitations. Furthermore, the applications included an option to generate fictitious data so that it would be possible to carry out these practical exercises when they could not be done in the laboratory, as it was the case during the COVID-19 pandemic. Fig. 2 shows different screens of one of the applications.

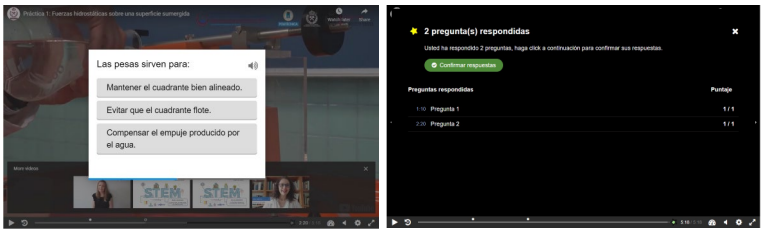


Fig 1. Example screens of one of the videos. The left screen shows a prompt, at an intermediate point of the video, with a question and the possible answers. The right screen appears at the end of the video and allows sending the results (green button).

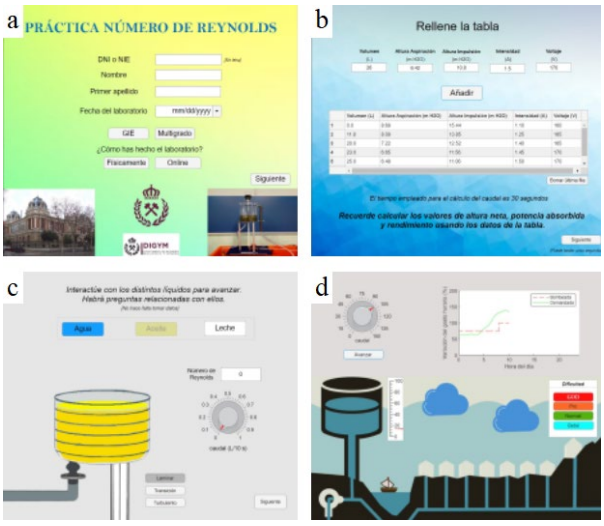


Fig 2. Example screens of the applications: a) input of personal data; b) input of experimental data; c) intermediate step of the resolution; d) picture of one of the games.

4 Results and Discussion

The numerical results consist of the rates of the students that passed the laboratory assignments with respect to the total number of students per degree and year. In

addition, the students' opinion and evaluation of the new tools was gathered by means of brief, voluntary and anonymous surveys through a link to Google Forms on the Moodle page of the course. The provided information helps to get a wider picture of the learning experience, including the identification of difficulties and problems that would need to be solved.

4.1 Students' results

Starting with the comparison of the experimental and control groups in the course of fluid mechanics in the year 2020–2021, Fig. 3 presents the pass rates obtained in the four works that make up the practical part of this subject, for each type of group and each degree. Students pass the exercises if they complete all the tasks and deliver their results, without any remarkable error.

In the GIE degree, the results of the experimental groups were clearly better in three of the four exercises while in the fourth one the results were very similar. In the case of MG, the results clearly increased with the new method in two of the four exercises while in the other two the marks were slightly worser. Both in GIE and MG, the improvement in the exercise of Bernoulli is especially noticeable, with pass rates changing from 44.0% to 76.3% and from 11.8% to 40.5%, respectively.

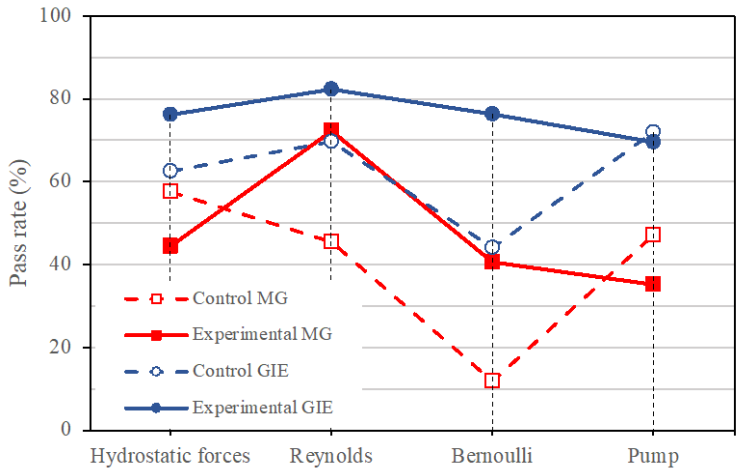


Fig 3. Results of the percentage of students that passed each laboratory exercise of the subject "Fluid Mechanics and Hydraulics" in the year 2020–2021, grouped by degree (GIE and MG) and by type of group (experimental and control).

The statistical significance of the observed differences was checked by chi-square (χ^2) tests [Gómez-Tejedor *et al.*, 2020; Zacharia and Olympiou, 2011], which evaluate the probability that the results really belong to differentiated groups attending to their distribution. In this context, that would be attributable to the different

followed methodology in each one. In the case of GIE, the differences in the two first exercises have a 90% significance level. In the exercise of Bernoulli, the significance level rises to 99% and, in the exercise of the Pump, there is no significant difference. Regarding MG, the differences in the exercises of Reynolds and Bernoulli were also significant at a 95% significance level while the Hydrostatic and the Pump exercises do not show significant differences.

In the following years, the new method was adopted for all the students and no distinction were made between groups any longer. However, the results can be compared with the previous years. Table 1 shows the pass rates for each of the laboratory exercises and each degree in the years 2021–2022 and 2022–2023. It can be observed that there is an increasing tendency over the time within each group, which confirms the robustness of this methodology.

With respect to the subject "Heat and Mass Transfer", taught only in the GIE degree, the practical work consists of two exercises. Results are available only for the last two years, as the laboratory was established in the year 2021–2022. That year, this laboratory activity was voluntary, and 64 students participated out of 124. The following year, all the 197 students registered in the course did the activity. Table 2 presents the pass rates for each exercise and year. The results of the first exercise are very similar in both years but, in the case of the second exercise, the pass rate increases by a 24% from the first year to the second one, which shows that the methodology seems to work with the students, despite the fact that they are "forced" to do the lab.

Table 1. Results of the pass rates (%) for each laboratory exercise in the last two years in the GIE and MG degrees in the subject "Fluid Mechanics and Hydraulics".

Degree	Year	Hydrostatic forces	Reynolds	Bernoulli	Pump
GIE	2021–2022	87.4	82.0	86.5	86.5
	2022–2023	91.8	87.8	85.7	87.2
MG	2021–2022	88.5	75.4	78.7	82.0
	2022–2023	88.5	87.4	86.2	85.1

Table 2. Results of the pass rates (%) for each laboratory exercise in the last two years in "Heat and Mass Transfer".

Year	Thermal conductivity	Difference of temperature
2021–2022	84.4	71.9
2022–2023	81.7	89.3

4.2 Students' perception (survey)

A voluntary survey was carried out each year to obtain the students' opinion about the laboratory activities in both courses. The responses were given on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The questions were: Q1: "I have learned things that I consider valuable"; Q2: "My interest in the

subject has increased thanks to the laboratory"; Q3: "The teaching material for the laboratory was well prepared"; Q4: "The workload and pace of the practical exercises was adequate"; and Q5: "The difficulty of the exercises has been in line with expectations".

Table 3 shows the mean values given by the students of the subject of fluid mechanics, grouping together the answers of the GIE and MG degrees. In the first year, the distinction between the control and experimental groups can be made, with 14 answers and 42 answers, respectively. In the year 2021–2022, 51 answers were obtained and, in 2022–2023, 31.

Table 3. Results of the surveys in "Fluid Mechanics and Hydraulics", with mean value and standard deviation in parenthesis. In Group, "C" denotes "control" and "E", "experimental".

Year	Group	Q1	Q2	Q3	Q4	Q5
2020–2021	C	3.4 (0.9)	3.2 (1.3)	4.2 (0.7)	3.9 (0.9)	4.4 (0.6)
	E	4.3 (0.7)	4.3 (0.9)	4.6 (0.9)	4.5 (0.7)	4.4 (0.8)
2021–2022	All	4.0 (0.8)	3.8 (1.0)	4.6 (0.6)	4.4 (0.8)	4.3 (0.7)
2022–2023	All	4.1 (0.8)	4.2 (1.2)	4.7 (0.6)	4.8 (0.6)	4.6 (0.5)

Comparing the answers of the control and experimental groups, the results of the different questions show that the new methodology motivated the students and increased their interest in the subject with a better perception of the workload. The difference of almost 0.7 points in question Q2 is especially noteworthy. The control group had a lower appreciation of the laboratory assignments. Positive results (4–5 points) are maintained over time, except for a slight decrease in questions Q1 and Q2 in the year 2021–2022.

Table 4 shows the results of the surveys in "Heat and Mass Transfer". In the year 2021–2022, there were 21 answers and, in the year 2022–2023, there were 25. The results for all questions are very similar in both years. In the first one, the activities were voluntary so the fact that the activities became compulsory did not affect the students' perception.

Table 4. Results of the surveys in the course "Heat and Mass Transfer", with mean value and standard deviation in parenthesis.

Year	Q1	Q2	Q3	Q4	Q5
2021–2022	4.1 (0.7)	4.3 (0.9)	4.7 (0.6)	4.6 (0.5)	4.6 (0.6)
2022–2023	3.9 (1.0)	4.0 (0.8)	4.6 (0.6)	4.8 (0.4)	4.7 (0.6)

Finally, the questionnaires also included open-ended questions that the students could freely answer whether positively or negatively. For both subjects, positive comments included the following (translated from the original in Spanish):

- "The taken measurements allow, in my opinion, a better understanding of the case under study, especially in the exercise of hydrostatic forces".
- "In this way, the process of reporting results is more interactive and enjoyable; in my case, I consider that I have learned more than if I had done it on paper".
- "See that what we learn in class has a real, practical application".
- "I have loved using the App as I consider it a different way of learning and also entertaining".

- "I liked the details of the minigame, very good! At first, I was not amused, and I ended up liking it!"

As can be seen, the students highlighted different aspects of the practical sessions, such as the application, the work in the laboratory, or teaching tasks. About 90 positive responses were received. The students also proposed improvements and described some frustrations:

- "I find the number of laboratory assignments to be low and doing more, I think, will help to better understand the subject and make the students enjoy it more".
- "I had several problems opening the applications with MATLAB. I was able to solve it but it was frustrating. It might be a good idea to create a forum so that future students can solve problems of the installation or use of the application".
- "If you do not have MATLAB installed, it takes a long time, and that increases considerably the time to do the work". "Mandatory use of the MATLAB app".

Some of the negative aspects and recommendations, such as the use of a help forum during the course or having better information about installing MATLAB, could be very useful to improve the students' performance. The number of negative responses or recommendations for improvement was 16.

5 Conclusions

A series of MATLAB applications and H5P videos were created to increase the digitization of the laboratory sessions of the subjects "Fluid Mechanics and Hydraulics" and "Heat and Mass Transfer" that are taught in different programs at the School of Mining and Energy Engineering of the *Universidad Politécnica de Madrid*. This project involved more than 500 second-year students over different years.

The applications made for the delivery of laboratory results aimed to reduce, as much as possible, the repetitive and laborious calculation work that is typical in the traditional method and focus more on improving the understanding of the physical phenomena behind. In addition, the videos that the students had to watch before the laboratory session promoted a better preparation for the activities and, therefore, the students could make the most of their time in the hands-on activity in the laboratory.

The results show that the pass rates of the students using the new methodology were generally higher than using the traditional one. A tendency of improvement of the pass rates can be observed over time. According to satisfaction surveys, the students also showed a positive opinion about the new methodology and resources. This is reflected in their answer to the question about the increase of their interest thanks to the laboratory, with a mean value of 4.12 in a scale up to 5.

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