International Journal of Engineering Education Vol. 40, No. 1, pp. 43–53, 2024
Printed in Great Britain

0949-149X/91 $3.00+0.00

A New Practical Approach for a Basic Electrical Instrumentation Lab to Enhance Student Engagement and Performance*

AINHOA REZOLA**, ANDONI BERIAIN, HÉCTOR SOLAR and NOEMÍ PÉREZ
Dept. of Electrical and Electronic Engineering, University of Navarra, TECNUN, San Sebastian, Spain

Basic energy and electricity concepts are often misunderstood by first-year engineering students. One of the main reasons for this is that these concepts are perceived as abstract, making it challenging for students to relate them to real-life situations. Experimental laboratories are designed to help students delve deeper into these concepts. However, the demand for more visual aids by students, coupled with their limited ability to grasp complex ideas, often leads to the perception that some labs are outdated and reinforces misconceptions. To address this issue, this article introduces a novel laboratory workbench and methodology aimed at enhancing basic electrical energy and instrumentation laboratory sessions. The approach utilizes a more visual and interactive platform that enables students to connect electrical concepts with real-life elements. Prior to attending the class, students watch instructional videos that demonstrate the practical procedures, following the Flipped Learning strategy. The results of this study reveal that students felt more confident during the laboratory sessions and exhibited a more active attitude, actively asking questions and defending their viewpoints. Professors also observed that time was utilized more effectively, allowing for a better understanding of topics and clarification of confusing content. Overall, the proposed lab sessions significantly improve the learning experience of first-year Physics students and foster their autonomy in learning.

Keywords: electrical engineering; laboratory; undergraduate; flipped classroom

1. Introduction

All undergraduate students pursuing engineering degrees at the University of Navarra are required to take Physics in their first year. Physics serves as a foundational course, providing students with the essential knowledge to comprehend advanced topics such as AC currents, transistors, and amplifiers. Among the various electricity topics covered, Direct Current (DC) Electric Circuits are emphasized. For many students, concepts like current, voltage, and power consumption are introduced for the first time in this course and are further developed in subsequent courses. Unfortunately, it has been observed that students often develop misconceptions regarding these fundamental concepts, which can significantly impact their understanding throughout their engineering curriculum.

Extensive research has been conducted on students' understanding of DC concepts in electric circuits [1–3]. Typically, engineering schools complement Physics lectures with laboratory practice sessions aimed at consolidating theoretical knowledge. In particular, the first-year Physics course at our University covers topics such as electricity, magnetism, and electromagnetic waves. It comprises theoretical sessions and two laboratory sessions, one focused on electricity and another dedicated to reinforcing the concepts of magnetism. These laboratory components are designed to complement the theoretical aspects of the course and provide a well-rounded educational experience for our first-year physics students.

Until now, the students' preparation for these laboratory sessions followed a traditional approach of reading a laboratory guide. The procedure and underlying physical laws were explained during the session, and students were expected to independently carry out the assigned tasks. Unfortunately, this laboratory session has remained largely unchanged for the past 20 years, yielding unsatisfactory results. Students often struggle with instrument handling, which hinders their ability to connect theoretical concepts covered in lectures to practical applications. Additionally, time constraints and large class sizes make it challenging to provide individualized feedback during these practice sessions.

Regrettably, it has been widely reported that such traditional laboratory sessions, rather than reinforcing lecture content, can exacerbate misconceptions [4, 5]. Several limitations have been identified in the development of these practice sessions. For instance, excessive time is spent by professors explaining procedures, physical laws, and the basic operation of measuring instruments. Students also invest significant time in preparing materials, resulting in minimal effective duration for the

** Corrsponding author: argarciandia@tecnun.es

* Accepted 21 November 2023.

practice session. Furthermore, in labs with a large number of students, long waiting times for individual attention from professors and repetitive questions among groups have been observed. Consequently, students often fail to grasp proper instrument handling techniques, leading to a superficial understanding of the subject's core concepts.

Given these challenges, we embarked on finding alternative approaches to enhance student training. Laboratory practices should ultimately enable students to solve abstract and complex engineering problems by applying acquired theoretical skills, rather than relying on a prescriptive recipe-based approach. Students should engage in hands-on activities, visualize concepts, and interpret the results they obtain. Furthermore, professors should guide the practice in a manner that allows students to identify common threads among different experiences and avoid mere data collection procedures.

The role of different laboratory types (development, research, and instructional) is pivotal in the effective training of future engineers. Among these, instructional laboratories are commonly employed, particularly in the early years of engineering studies, to reinforce theoretical concepts in a controlled setting. Instructional labs are more manageable, yielding uniform results that simplify the correction of practical exercises, making them ideal for large groups. Lab in Box experiments have been proposed by other schools to provide hands-on experiences even if there are no physical labs available. Although we believe this is a good solution in some particular situations, this type of labs do not offer a proper study of electrical signals rather than through simulations. Moreover, there are safety issues related to electrical signals that cannot be addressed at home. Therefore, we believe that on-site instructional laboratories are the ideal match for the concepts we aim to explore through our lab.

In addition to designing the lab session content, increasing student interest and motivation in the laboratory is crucial. According to [6], incorporating hands-on activities and visualization techniques can enhance student engagement and promote a deeper understanding of abstract and complex engineering problems. Furthermore, the use of instructional videos and technology can enhance students' learning experience and visualization by providing visual demonstrations and allowing them to review concepts at their own pace.

Moreover, the Flipped Learning methodology has proven to be a valuable tool in enhancing student motivation and learning during laboratory lessons [5, 7]. By employing the Flipped Learning methodology, students are expected to participate more actively and independently, gain confidence in the laboratory setting, improve efficiency, and develop a deeper understanding of the tasks and their underlying principles [5, 7–11].

Taking all these factors into account, this article presents a new lab session aimed at introducing first-year students to basic electrical concepts, such as resistance, voltage, current, and power, using familiar elements from their daily lives. Additionally, the new lab session incorporates the use of a signal generator, oscilloscope, and multimeter, supplemented with instructional videos following a Flipped Learning strategy.

The primary objective of this work is to enhance the practice sessions of the Physics course by making them more engaging, promoting learning outside the classroom, and optimizing the time dedicated to understanding and clarifying theoretical concepts covered in lectures. The remainder of this article is organized as follows: Section 2 outlines the objectives and assessment of the proposed laboratory session. Section 3 describes the laboratory session and the methodology employed. Section 4 presents the obtained results, and finally, Section 5 summarizes the main conclusions of this study.

2. Objectives and Assessment

The first step in designing a laboratory is to clearly define the desired objectives, as clear learning objectives are essential for effective learning and assessment. [12] provides detailed insights into different types of objectives for engineering instructional laboratories, making their publication an excellent resource for designing labs based on student outcomes. Furthermore, the assessment of students will be based on these defined objectives.

The primary objective of this work is to enhance the practical laboratory experience of a Physics subject taught in the first year of an engineering degree, with a focus on achieving three main outcomes. Firstly, it aims to improve the knowledge and understanding of the students of basic electrical concepts such as current, power, and voltage that are abstract and hard concepts for the students. Secondly, it seeks to optimize laboratory time, ensuring maximum time dedicated to practical aspects. Lastly, it aims to motivate students and cultivate their interest in electricity-related topics.

Regarding assessment, it is crucial to adopt an evaluation methodology that effectively measures both student performance in the lab and their learning outcomes. Additionally, for the Flipped Learning strategy to be successful, it is essential to evaluate the activities intended to be completed before the lab sessions. Therefore, careful consideration of these factors is necessary to design and implement an effective assessment for our students.

3. Methodology

This section describes the design methodology used for the laboratory session, the actual design of the session, its implementation and evaluation.

3.1 Design of the Lab

As mentioned in the objectives section, we believe that a correct design of the objectives aimed in a lab is key to obtain correct learning outputs.

Therefore, following the work of [12], for the design of this lab session we defined six objectives that were translated to specific tasks in the session. These objectives are described below.

- **Objective 1**: *Instrumental*. Apply appropriate instruments and techniques to take measurements of physical quantities. This goal will be achieved by asking the students to take voltage and current measurements with the multimeter. Also, the students will have to measure frequency and amplitude of an AC signal using an oscilloscope.
- **Objective 2**: *Models*. Validate the relationship between measured data and basic principles. In the lab the students will have to validate that Ohm's law is fulfilled.
- **Objective 3**: *Data Analysis*. Collect, analyze and interpret data. The students will have to collect all the data measured, calculate the value of the resistance of the different elements that are characterized and compare the different lightning technologies presented in the lab.
- **Objective 4**: *Learn from failure*. Identify unsuccessful outcomes due to faulty processes and re-engineer effective solutions. We will ask the students to create an overload in the system and to rethink a solution using renewable energies.
- **Objective 5**: *Sensory Awareness*. Use the human senses to gather information and to make judgements about real-world problems. We will ask students to apply what they learn in the lab to a real case study.
- **Objective 6**: *Engagement*. To attract the interest of the students to the study of electricity related issues. We will design a platform in which students will find everyday electrical components they are familiar with.

In order to evaluate the fulfillment of these objectives, three different types of assessments are used:

- **Data acquisition and analysis**. In this laboratory session students will be asked to measure different voltage drops and currents passing through different electrical components. With these measurements, they will have to calculate the resistance and the power consumption of each component for further analysis. The values obtained from these measurements will be assessed at the end of the lab session. The aim of this assessment is twofold: first, to check whether they learned how to perform the measurements and secondly to assess their critical thinking by analyzing the values that they obtained.
- **Direct assessment by the instructors during the lab session**. Once the students have reached the end of the lab assignment, the lab instructors will give them a questionnaire to fulfill in order to assess their performance. Assessing the learning experience of the lab can enhance the conceptual understanding of the theory–practice relationship, a higher level reasoning skills and the development of their practical competence in laboratory work. Moreover, the assessment will help us assure the students have gained a deep understanding of abstract concepts and theories.
- **Satisfaction test**. We consider that in order to achieve continual quality improvement, any feedback from the student is vitally important. Therefore, to monitor their experiences and satisfaction levels, the students were asked to fill in a satisfaction survey at the end of the semester. This survey will also help to identify potential improvements of the laboratory session.

In the following sections the design of the components, the procedure and the strategies for the lab session are explained in detail.

3.2 Laboratory Session Description

In our course, which typically enrolls about 200 students, the laboratory sessions extend over eight days, with the goal of enhancing learning and ensuring personalized attention. To achieve this, we organize the students into eight groups. Each day, roughly 36 students participate in the lab, working in pairs.

In order to fulfill all the established objectives for the laboratory session, we have developed a dedicated workbench specifically designed for conducting the required measurements. This workbench consists of four familiar elements: a resistor, a halogen lamp, an LED lamp, and a fan. By utilizing these real-life elements, our intention is to enable students to focus on understanding the electrical concepts rather than spending their time trying to comprehend the intricate workings of complex or uncommon components. Moreover, by using recognizable electrical components, we aim to spark the

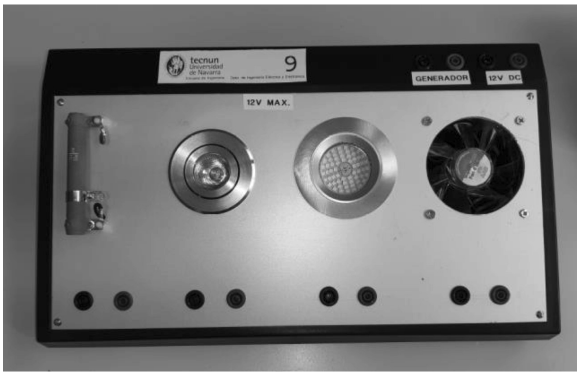

Fig. 1. Workbench with a resistor, a halogen lamp, an LED lamp and a fan.

students' curiosity and encourage them to ponder the inner workings of these elements. It is important to note that the workbenches used in our laboratory are made by our technicians that handle mechanical, electrical and electronic equipment. The students find the modules ready to work in the lab.

The workbench operates on a 12 VDC power supply, while the available power source for the students is a standard 230 VAC supply. To bridge this voltage gap, we have incorporated an AC/AC converter that transforms the 230 VAC input into 12 VAC, followed by an AC/DC converter that converts the 12 VAC to 12 VDC. This setup enables students to safely work with the appropriate voltage level on the workbench. Furthermore, to provide a practical example, we have included a magnetothermic switch, which simulates a scenario where the power demand exceeds the capacity provided by the electrical company. This component allows us to discuss the implications of such situations and their relevance to household electrical systems.

Fig. 2 illustrates the architecture of the AC/DC converter, which is intentionally left open to facilitate the explanation of the working principle of a diode bridge. This configuration also allows students to perform measurements using an oscilloscope, as we will discuss in detail later.

Fig. 2. 230 to 12 V AC/AC and AC/DC converters with magnetothermic switch.

The laboratory session begins by introducing the students to the various components of the workbench and guiding them through the process of connecting the power supply to the first element, which is the resistor. Subsequently, the students are instructed to observe and analyze the voltage signals at both the input and output of the AC/DC converter using an oscilloscope. This initial experiment serves to achieve objectives 1 and 3, as it allows students to gain hands-on experience with an oscilloscope, familiarize themselves with AC/DC concepts, and understand the distinction between effective (RMS) voltage and instantaneous voltage.

The next stage of the lab session involves characterizing the voltage drop and current flow across the four components of the workbench. For this purpose, the students utilize a multimeter to measure these parameters. Fig. 3 illustrates the setup used to measure the current passing through the fan, serving as an example. After obtaining measurements for voltage and current in all the components, the students are tasked with calculating the resistance of each component and their power consumption. They are then prompted to compare these values among the different components. Additionally, the students are instructed to repeat these measurements and calculations for the AC part of the circuit and compare the results with those obtained in the DC part. This second stage of the lab session achieves multiple objectives related to objectives 1, 2, and 3. The students gain proficiency in making current and voltage measurements using a multimeter, develop an understanding of power consumption, and become familiar with series and parallel measurements.

The third stage of the lab session is designed to achieve objectives 4 and 5. The goal is to develop the ability of the students to learn from failure and to establish connections between laboratory work and real-life situations. To accomplish this, the students

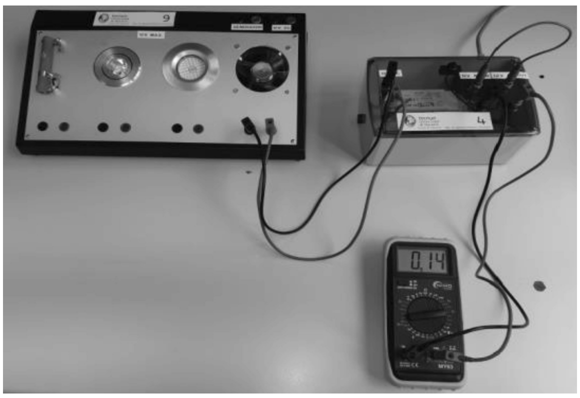

Fig. 3. Setup for current measurement on the fan.

are instructed to connect all four components of the workbench simultaneously and observe the outcomes. The magnetothermic switch is calibrated to support a lower current than that required by all the components, causing it to switch off after a few seconds of normal operation. Subsequently, the students engage in a discussion to analyze what is happening and how this scenario relates to real-life situations.

Following this discussion, the students are instructed to disconnect the component with the highest power consumption and connect it to a solar panel. They then reconnect all the components of the workbench and observe the effects of the solar panel. This part of the lab session provides an opportunity to briefly explain the benefits of installing solar panels in residential settings, thus fulfilling objective 6, which aims to increase students' interest in electricity-related issues.

The final part of the lab session is designed to fulfill objectives 1 and 5. The main objective is to demonstrate how a signal generator works and explain the consequences of varying the duty cycle of a signal. To achieve this, the students are asked to connect the fan to the signal generator and adjust both the frequency and duty cycle of the input signal. The fan is equipped with lights that visually illustrate the effects of these parameters, primarily changes in rotation speed. This experiment provides an opportunity to explain how a fan and motor can be controlled using a pulse-width modulation (PWM) signal in a simple and visually engaging manner.

Additionally, objectives 5 and 6 are addressed through an activity that the students undertake after completing the measurements. Each group is assigned a real-life situation and is tasked with discussing and performing calculations to propose a solution. Examples of these scenarios include electrical household appliance labeling, calculating power and cost savings using solar technology, or estimating the costs associated with different electricity supply contracts, among others. After discussing these cases, each group presents their conclusions and demonstrates their calculations to the professors, fostering critical thinking and practical application of concepts. This activity serves to fulfill objectives 5 and 6 by engaging students in real-world problem-solving and deepening their understanding of electricity-related issues.

3.3 Flipped Learning Strategy

In order to optimize the time the students spend in the laboratory and avoid the need for them to spend valuable lab hours understanding the working principles of the equipment or the theoretical basis of the experiments, we have developed concise instructional videos. These videos serve as a preparatory tool for the students before their lab session and provide a clear explanation of the main commands and functions of the oscilloscope, multimeter, and signal generator – the equipment they will be using during the lab. Additionally, we have created a video specifically addressing the concept of duty cycle, which students often find challenging to grasp. To enhance the visual presentation of the videos, we utilized a lightboard.

All students are required to watch these videos prior to attending the lab session. To ensure comprehension and preparedness, quizzes have been incorporated into the videos. These quizzes serve as a motivation for students to engage with the content, as their performance in the quizzes contributes to a small portion of their final grade. Edpuzzle was employed as a platform to embed questions within the videos. This platform allows professors to track individual student progress, monitor the time taken to complete the lesson, and impose restrictions such as preventing fast-forwarding or switching tabs. By leveraging Edpuzzle, we gained valuable insights into student engagement, including the number of students who watched the video, the percentage of the video they watched, when they watched it, and their accuracy in answering the embedded questions. This data enabled us to identify challenging concepts and allocate more time during the lab session to address these areas, while facilitating a faster pace for topics that students already understood.

In addition to the pre-recorded instructional videos, we also created detailed videos demonstrating the proper handling of the laboratory equipment. Each device used in the lab was accompanied by a QR code, which, when scanned, directed the students to a video explaining its operation. These videos covered topics such as voltage and frequency measurements using markers on an oscilloscope, voltage, current, resistance, and continuity measurements with a multimeter, and generating signals with different shapes, frequencies, and duty cycles using a function generator.

Students can easily access detailed information about the laboratory sessions through our online course platform, where they can find the specifics of the lab, including the complete lab manual and mandatory instructional videos they need to watch prior to the practical sessions. These videos complement the traditional laboratory guide rather than replacing it. This way, the explanation that professors normally give in the lab was replaced by previous work that the students do at home. The students are able to watch the video clips anytime and anywhere with Internet access, rewind, forward, pause, and skip the video recordings according to their pace of learning. They can stop the recording to take notes and play the videos multiple times, which provides opportunities to revisit content to revise, reinforce key concepts or spend more time with problematic material, as other authors have proved to be advantageous for the students [9, 10, 13].

We believe that by shifting the explanation and demonstration of equipment operation to the pre-lab videos, we transformed the in-person lab session into a time for discussion, clarification, and practical application of the acquired knowledge. In-class explanations were reduced to addressing specific student queries, thereby maximizing the effectiveness of the practice session [8, 10, 13].

3.4 Assessment and Feedback

The proper design of the lab assessment plays a crucial role in motivating students to complete the required tasks both before and during the lab session. Prior to the practice session, students are expected to independently engage with the assigned tasks, which include watching the videos and answering related questions. The quality of their responses and the level of completion are taken into consideration when determining their final grade.

During the lab session, where students work in pairs, professors assess their commitment and diligence in carrying out measurements, setups, and calculations. Additionally, the students' performance in analyzing real-life case studies is also a factor in determining their grade, with students receiving an A, B, or C based on their answers.

Furthermore, students are asked to participate in various satisfaction surveys to provide feedback on the lab session. The results of these surveys will be discussed in the subsequent section of the article.

4. Results and Discussion

This section presents an analysis of the results obtained from the implementation of the new laboratory session proposed in this study. It examines the outcomes of the pre-recorded videos, the grades achieved in the lab session, and the results of the satisfaction surveys. Furthermore, the section also explores the impressions and observations of the professors involved in the implementation.

4.1 Pre-recorded Videos

As explained previously, EdPuzzle was utilized to create a questionnaire related to the pre-recorded videos that students were required to watch prior to attending the laboratory session. This tool provided valuable insights into the students' engagement with the videos, including information on the duration of video viewing, the last access time, and the submission of the assignment. Furthermore, since the videos incorporated multiple-choice questions, it was possible to gather data on the percentage of students who answered these questions correctly.

Out of the 209 students who participated in the practice session, it was observed that 81% of them watched at least one video, while 73% viewed all three videos. Regarding the multiple-choice questions in the first video, which focused on the function generator, Fig. 4 demonstrates that 95% of the students answered both questions correctly. Additionally, only 1% of the students discontinued the video before reaching the first question.

The second video, which focused on the multimeter, included three questions. As illustrated in Fig. 4, 94% of the students successfully answered at least two questions correctly. Notably, none of the students provided incorrect answers to all three questions, and only 3% of the students did not answer any of the questions.

The third video centered around the oscilloscope and comprised two questions. Fig. 4 demonstrates that a majority of the students, specifically 74%, accurately answered both questions. Interestingly, only 3% of the students failed to answer both questions correctly. Additionally, 5% of the students did not attempt any of the questions.

Upon analyzing the high percentage of correctly answered questions, it can be concluded that the videos were presented in a clear and comprehensible manner, enabling students to follow along easily. The inclusion of quizzes within the videos proved to be beneficial in helping students grasp the concepts discussed.

4.2 Grades of the Practice Session

As previously mentioned, each group was presented with a real-world scenario that pertained to the concepts covered in the lab session. They were tasked with discussing the situation and conducting

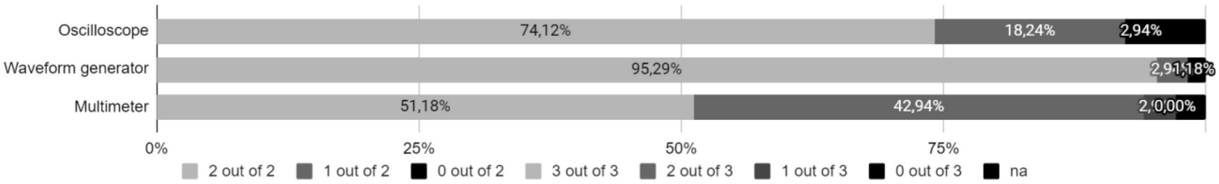

Fig. 4. Quizzes results.

calculations to devise a solution. The professors evaluated their responses and performance during the lab session, assigning one of three possible grades: A, B, or C. The highest grade achievable was an A, while the lowest was a C.

Remarkably, 85.3% of the students attained an A grade, indicating a high level of proficiency and understanding. Additionally, 12% of the students received a B grade, signifying a commendable performance. Encouragingly, only 1.7% of the students were assigned a C grade, demonstrating a minimal number of students who struggled to meet the expected standards.

4.3 Survey Results

At the conclusion of the semester, after the final exam, students were invited to participate in a voluntary survey to provide feedback on the new laboratory session. Out of the 209 students who completed the lab session, 120 valid survey responses were received. Prior to administering the survey, students were informed that its purpose was to assist the professors in enhancing the laboratory session for future students. The survey comprised a total of twenty questions, with eight pertaining to the pre-recorded videos, another eight related to the QR videos, and the remaining questions addressing general aspects such as students' knowledge, their perception of the lab session, and its methodology. The subsequent subsections outline the findings obtained in each category.

4.3.1 Perceived Benefits of Pre-recorded Lectures

Figs. 5 to 7 present the outcomes of the surveys concerning the pre-recorded videos that students were required to view prior to attending the laboratory. The percentage agreement for each response option was determined by combining the number of Agree and Strongly Agree responses.

Fig. 5 demonstrates that nearly 80% of the students agreed that the pre-recorded videos aided them in becoming more acquainted with the equipment they would be utilizing in the laboratory session. In Fig. 6, it can be observed that over 70% of the students found the videos to be technically concise and clear, while less than 10% disagreed with the ease of following them. Furthermore, Fig. 6 indicates that 64% of the students believed that the videos contributed to their improved readiness for the lab session, and 60% reported feeling more confident before attending the session as a result of watching the videos.

Based on the survey results, it can be concluded that the activity has had a positive impact, as the majority of students expressed positive views about the videos. As shown in Fig. 7, most students agreed that the videos helped them to complete the practice session in a more time-efficient manner. Additionally, over half of the students indicated a preference for this new methodology compared to the traditional style where equipment is explained on-site.

The authors of the study believe that the inclusion of pre-recorded laboratory lectures had a positive impact on their laboratory classes. The availability of these lectures allowed for more dedicated lab time to complete the assigned tasks. Moreover, the students expressed increased confidence in the laboratory class and their ability to successfully undertake the assigned work.

This finding highlights the benefits of incorporating pre-recorded lectures as a complementary

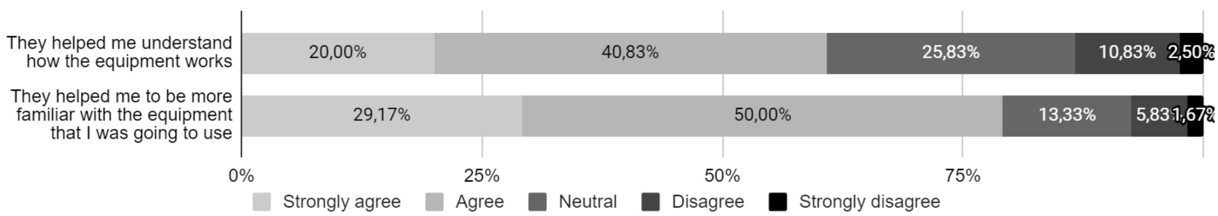

Fig. 5. Survey answers for the pre-recorded videos (1).

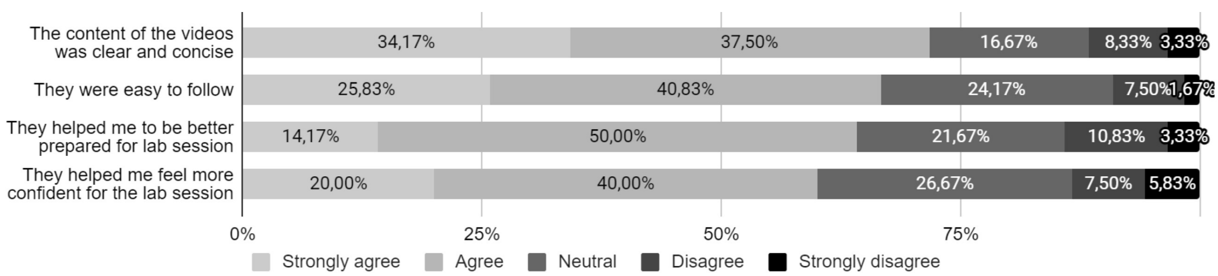

Fig. 6. Survey answers for the pre-recorded videos (2).

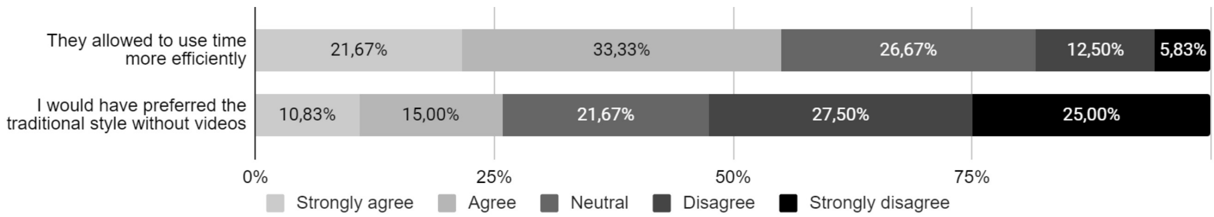

Fig. 7. Survey answers for the pre-recorded videos (3).

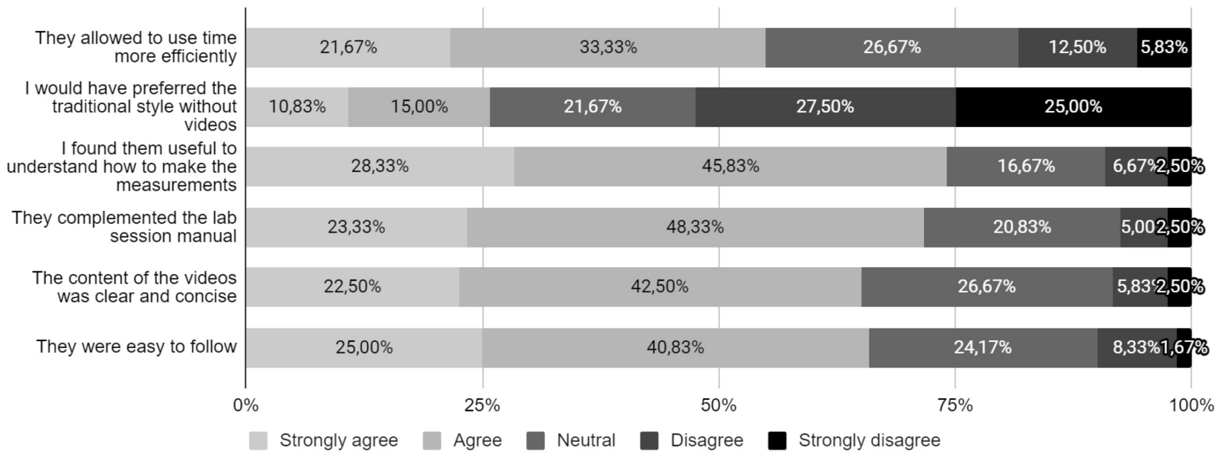

Fig. 8. Survey answers for the QR videos (1).

resource in the laboratory learning environment. By providing students with the opportunity to review and familiarize themselves with the theoretical concepts and practical procedures before the actual lab session, they can optimize their time and engage more effectively in the hands-on activities.

It is worth noting that the authors' perspective aligns with the overall objective of enhancing student learning outcomes and improving their experience in the laboratory setting. By leveraging pre-recorded lectures, educators can create a more structured and efficient learning environment, fostering students' confidence and competence in performing laboratory tasks.

4.3.2 Perceived Benefits of the QR Videos

The results of the second survey, which focused on the videos explaining the functionality of the equipment, are presented in Figs. 8 and 9. These figures provide insights into students' perceptions and experiences related to these instructional videos.

Fig. 8 illustrates that over 70% of the students found the videos useful in understanding how to make measurements, and they considered them to be a valuable complement to the contents of the laboratory guide. This indicates that the videos effectively supported students' comprehension of the measurement procedures.

Furthermore, Fig. 8 also indicates that more than 60% of the students regarded the videos as clear and easy to follow. This suggests that the instructional videos were effective in presenting the information in a coherent and understandable manner. Additionally, the majority of students felt that the videos helped to clarify the procedures involved in making measurements, indicating their usefulness in facil-

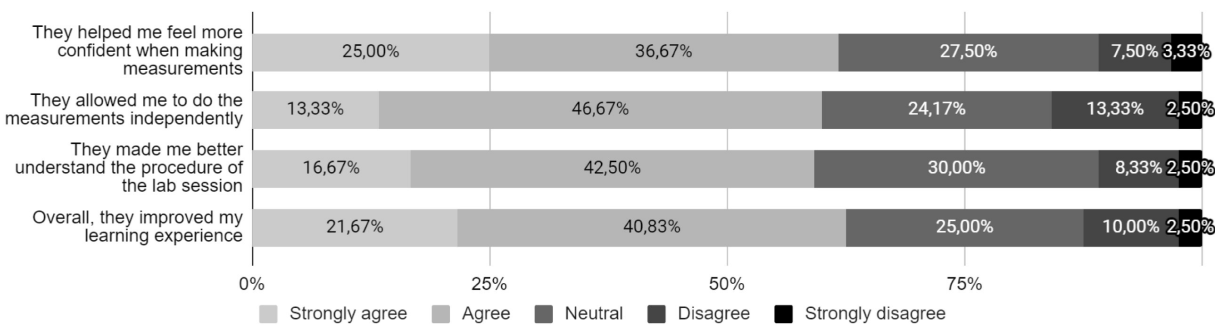

Fig. 9. Survey answers for the QR videos (2).

itating students' understanding and execution of the practical tasks.

Fig. 9 reveals that more than 60% of the students reported feeling more confident and independent when conducting the measurements due to the videos. This demonstrates the positive impact of the videos on students' self-efficacy and ability to perform the required measurements with greater assurance.

Overall, these survey results indicate that the videos explaining the functionality of the equipment were well-received by the students. They found the videos useful, clear, and effective in enhancing their understanding of measurement procedures, as well as boosting their confidence and independence in carrying out the measurements.

4.3.3 General Questions

The students also filled in a survey regarding their knowledge about electricity before and after attending the laboratory session and their experience with the laboratory equipment. The results of this survey are summarized in Figs. 10 and 11.

According to the survey results depicted in Fig. 10, a small percentage (4%) of the students had prior experience using all the equipment involved in the laboratory session. This suggests that for the majority of the students (around 77%), it was their first time using this specific set of equipment.

Fig. 11, on the other hand, demonstrates that despite the limited prior experience with the equipment, a significant portion of the students (63%) reported an improvement in their overall knowledge about electricity after completing the practice session. This finding indicates that the laboratory session successfully contributed to enhancing their understanding and comprehension of the subject matter.

These results are encouraging as they indicate that the laboratory session effectively fulfilled its purpose of improving students' knowledge about electricity. Despite the majority of students being unfamiliar with the equipment prior to the session, their experience with the lab equipment, combined with the instructional videos and practical exercises, resulted in a positive impact on their understanding of the topic.

These findings demonstrate the effectiveness of the laboratory session in not only providing practical experience with the equipment but also in enhancing students' knowledge of electricity. By actively engaging with the equipment and participating in hands-on exercises, students were able to expand their understanding and develop a stronger grasp of the concepts.

4.4 Professors Perception

Based on our observations and analysis of the laboratory session, as well as the feedback from the laboratory technicians, several key points can be highlighted:

Increased Student Confidence: Compared to previous years, students exhibited greater confidence when performing tasks in the laboratory. This can be attributed to the availability of instructional videos through QR codes, which allowed students to refer to the content while instructors were

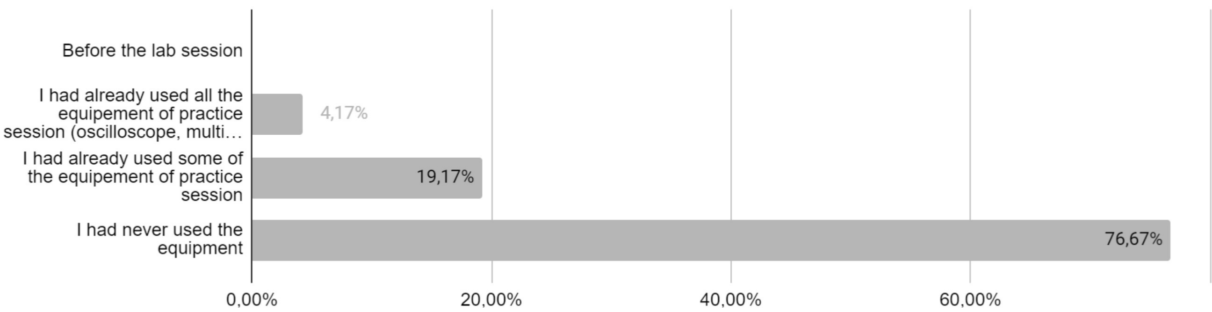

Fig. 10. Before the lab session.

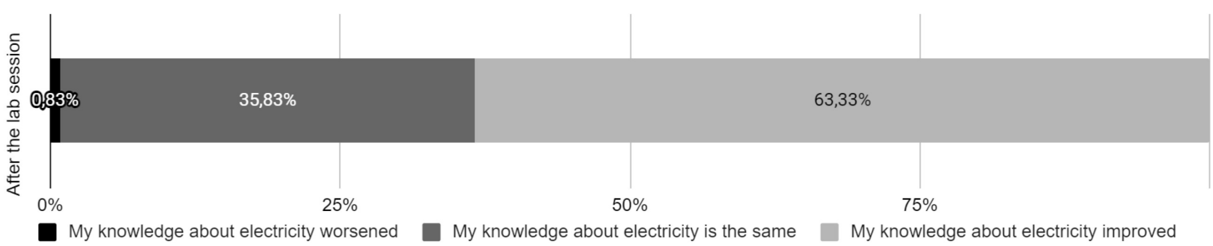

Fig. 11. After the lab session.

occupied with other students. The reduced waiting time enabled students to progress more independently and efficiently, resulting in a higher level of confidence in their abilities. The optimized use of class time also contributed to improved task completion.

Improved Preparedness: A significant difference noted compared to previous years was that students were able to begin measurements immediately upon entering the laboratory. This was attributed to their prior viewing of the videos, which better prepared them for the tasks. Considering that it was their first encounter with the laboratory equipment and they often feel insecure, the videos helped alleviate their concerns and provided them with a clearer understanding of the requirements of the lab session. This enhanced preparation allowed for a smoother transition into the practical tasks.

Enhanced Understanding through Demonstration Videos: The utilization of demonstration videos accessible through QR codes fostered greater engagement among the undergraduates. These videos made the practical procedures more comprehensible, providing students with a visual reference to support their understanding. The ability to pause, rewind, and take notes during the videos contributed to a more efficient use of time during the practice session. Students could review specific sections as needed, enabling them to grasp the content more effectively.

Challenges with Student Engagement: While the overall perception of the new Flipped Learning methodology was positive, it is important to acknowledge that not all students embraced this approach. Approximately 19% of students did not watch any of the videos prior to the practice session. This suggests that accommodating diverse learning styles and preferences remains a challenge. Some students may still require face-to-face explanations to fully comprehend concepts and procedures. Additionally, the Flipped Learning methodology demands academic maturity and responsibility, which some students may not have developed fully. Thus, this approach may pose difficulties for students who lack strong study skills.

Time Investment and Future Benefits: The implementation of the new laboratory session with the new methodology initially required a substantial time investment. However, once the instructional materials were created, the professors spent less time preparing for each lab session compared to previous years. Additionally, future iterations of the course will require significantly less preparation time, as the videos and class activities can be reused from year to year. This indicates the potential for long-term time savings and improved efficiency in course delivery.

Considering all these factors, it can be concluded that both the students and the professors generally perceive the new laboratory session and methodology in a positive light. The increased confidence, improved preparedness, enhanced understanding, and time efficiency achieved through the implementation of instructional videos and the Flipped Learning approach contribute to a favorable overall perception of the new laboratory session.

5. Conclusions

Engineering education places a strong emphasis on practical training, and laboratory sessions play a vital role in preparing future engineers. However, many engineering schools have maintained the same laboratory sessions for decades, particularly those focused on fundamental science and technology concepts. This static approach, combined with students' preference for visual learning and challenges in grasping abstract concepts, has rendered certain electricity-based labs obsolete and ineffective in promoting conceptual understanding.

To address this issue, this article introduces an innovative laboratory workbench and methodology designed to enhance basic electrical and instrumentation laboratory sessions for undergraduate engineering students. The traditional approach to instrumentation labs has been replaced by a more interactive and visually engaging platform, allowing students to gain a better understanding of basic electrical concepts and establish connections with real-world applications. Additionally, instructional videos demonstrating practical procedures are provided, which students watch prior to attending the lab session following a Flipped Learning strategy.

Analysis of student performance, grades, and survey responses indicates a generally positive response to this new methodology. Students find the video content to be well-explained and helpful in preparing for the lab session. Overall, the videos increase students' confidence and competence in undertaking the lab tasks. Professors also benefit from this approach, as it allows for more efficient use of time during the lab session. With basic explanations already covered in the videos, professors can dedicate more time to exploring topics in greater depth and clarifying any areas of confusion. These findings demonstrate the successful implementation of the Flipped Learning methodology in preparing students for Physics laboratory sessions.

Moreover, it is essential to recognize the role of professors in cultivating autonomous learning in students. Engineering students must develop the ability to learn independently, and the laboratory session proposed in this article serves as a catalyst for fostering self-directed learning among students.

References

1. P. V. Engelhardt and R. J. Beichner, Students' Understanding of Direct Current Resistive Electrical Circuits, *American Journal of Physics*, **72**, pp. 98–115, 2004.
2. D. Holton, A. Verma and G. Biswas, Assessing student difficulties in understanding the behavior of AC and DC circuits, 2008.
3. V. T. Sanches, G. G. Costa, J. F. Santos and T. Catunda, Analysis of Engineering Students' Common difficulties with DC electric circuits in an Inquiry-based laboratory, *Revista Eletrônica Engenharia Viva*, **5**, pp. 13–22, 2013.
4. T. Long, J. Logan and M. Waugh, Students' Perceptions of the Value of Using Videos as a Pre-class Learning Experience in the Flipped Classroom, *TechTrends*, **60**, pp. 245–252, 2016.
5. T. W. Teo, K. C. Tan, Y. K. Yan and Y. C. Teo, How flip teaching supports undergraduate chemistry laboratory learning, *Chemistry Education Research and Practice*, **15**(4), pp. 550–567, 2014.
6. E. Rutz, R. Eckart, J. Wade, C. Maltbie, C. Rafter and V. Elkins, Student Performance and Acceptance of Instructional Technology: Comparing Technology-Enhanced and Traditional Instruction for a Course in Statics, *Journal of Engineering Education*, **92**(2), pp. 133–140, 2013
7. J. A. Gómez-Tejedor, A. Vidaurre, I. Ausina, J. Mateo, J. Dueñas, R. Martinez-Sala, S. Quiles and J. Riera, Data set on the effectiveness of Flip Teaching on engineering students' performance in the physics lab compared to Traditional Methodology, *Data in Brief*, **28**, 104915, 2020.
8. J. A. Gómez-Tejedor, A. Vidaurre, I. Tort-Ausina, J. Molina-Mateo, M. Serrano, J. M. Meseguer-Dueñas, R. M. Martínez Sala, S. Quiles and J. Riera, Effectiveness of flip teaching on engineering students' performance in the physics lab, *Computers & Education*, **144**, 103708, 2020
9. B. Kerr, The flipped classroom in engineering education: A survey of the research, *2015 International Conference on Interactive Collaborative Learning (ICL)*, Florence (Italy), September 2015, pp. 815–818, 2015
10. S. Robinson, G. Roland, C. Bosse and E. Zayas, Effectiveness of flipped classroom techniques in an advanced laboratory physics course*, 2015 Conference on Laboratory Instruction Beyond the First Year of College*, College Park, MD, July 2015, pp. 92–95, 2015.
11. Y. Sánchez-Palencia, D. Bolonio, F. Barrio-Parra, M. Izquierdo-Díaz and E. García, The experience of flipped classroom in chemical laboratory classes for engineering students: QUIMETUBE, *INTED2019 Proceedings*, IATED, Valencia, Spain, March 11–14, pp. 460–467, 2019
12. L. D. Feisel and A. J. Rosa, The Role of the Laboratory in Undergraduate Engineering Education, *Journal of Engineering Education*, **94**(1), pp 121–130, 2005.
13. G. S. Mason, T. R. Shuman and K. E. Cook, Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in an Upper-Division Engineering Course, *IEEE Transactions on Education*, **56**, pp. 430–435, 2013.

Ainhoa Rezola received her MSc and PhD degrees in Telecommunication Engineering from Tecnun – University of Navarra in 2013 and 2017, respectively. She joined the Electronic and Communication department at CEIT research center in 2013. Since 2013 her research has focused on the design of digital systems, especially on the design and implementation of hardware platforms based on microprocessor and FPGA. In 2019 Ainhoa was a Visiting Postdoctoral Researcher in the Department of Electrical and Computer Engineering at the University of California, Santa Barbara (UCSB). She is currently an Associate Professor with the Electrical and Electronic Engineering Department, Tecnun – University of Navarra.

Andoni Beriain (Member, IEEE) received the MSc and PhD degrees in telecommunication engineering from Tecnun – University of Navarra, in 2008 and 2013, respectively, with a focus on low-power sensor interface design. From 2013 to 2018, he was devoted to the design of the analog front-end and mixed-signal blocks of a sensor enabled passive RFID chip marketed as Rocky100 by Farsens Company. He is currently an Associate Professor with the Department of Electrical and Electronic Engineering, Tecnun – University of Navarra. His current research interests include long-range RFID sensor applications and energy harvesters and power management units for autonomous sensor nodes.

Hector Solar received the MSc degree in telecommunication engineering from the University of Pais Vasco, Bilbao, Spain, in 2002, and the PhD degree in electronic engineering from Tecnun – University of Navarra, in 2007. From 2007, he was a Researcher with the Electronics and Communications Division of CEIT. Through CEIT, he has collaborated in the design RF/mm-wave, low-power sensors and RFID devices in CMOS. He is currently an Associate Professor with the Electrical and Electronic Engineering Department, Tecnun – University of Navarra. His research interests include CMOS RF/mm-wave integrated circuit design for communication and quantum readout and control, and low power analog circuit design with a special emphasis on batteryless sensor nodes.

Noemí Pérez received the MSc degree in electronic engineering from the University of Valladolid in 2004 and the PhD degree from the University of Navarra in 2008. From 2004 to 2011, she worked at the Microelectronics and Microsystems Department in CEIT. Her research was focused on the laser structuring of functional materials. She joined Tecnun in 2012, where she is currently a Professor and a Researcher in the Electrical and Electronic Engineering Department. Her actual research interests include wireless RFID and chipless sensors.