

CAPÍTULO 9

ELECTROHACK: FOSTERING ELECTRICAL ENGINEERING SKILLS THROUGH HANDS-ON CHALLENGES

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INTRODUCTION

The growing emphasis on active learning in electrical engineering education reflects a shift from traditional lecture-based instruction toward more interactive, student-centred methodologies. Hands-on projects, particularly in the form of Project-Based Learning (PBL), case-based learning (CBL), and simulation-based exercises, are at the forefront of this evolution. These approaches not only enhance technical proficiency but also foster critical thinking, collaboration, and problem-solving skills. In this chapter, a hands-on project is presented in the form of a hackathon for undergraduate students enrolled in Analysis of Electric Networks courses within the School of Industrial Engineering at University of Málaga, Spain.

Current state of the art for the subject or course for which the project is proposed

Hands-on projects provide a crucial link between theory and practice in electrical engineering. Unlike traditional lectures, which can struggle to engage students deeply, hands-on learning actively involves students in the educational process, ensuring that they apply concepts in real-world contexts. Projects like Khan, Haque, Sachdeva, & Morgan (2022), which use a microgrid to teach Smart Grid technologies, demonstrate how PBL enhances both knowledge retention and practical skills. Similarly, the project on electric vehicle development by Ariza & Olatunde-Aiyedun (2023) highlights the impact of interdisciplinary, hands-on approaches. Students working on complex, real-world problems, such as renewable energy integration into electric vehicles, develop both technical and soft skills. These projects maintain the focus on core engineering concepts while immersing students in practical applications, helping bridge the gap between classroom learning and industry expectations.

One of the most significant advantages of hands-on learning projects is their ability to simulate real-world engineering environments using augmented reality or hardware in the loop approaches. Molina, Ponce, Baltazar Reyes, & Soriano (2019) showed that smart grid laboratories, supported by fuzzy logic and real-time simulations, not only increased student understanding of grid technologies but also reinforced industry-relevant competencies. Similarly, Flores & Villicaña (2018)

integrated external collaboration by encouraging students to present their project results at international conferences, fostering a professional mindset while sharpening both technical and communication skills. These projects connect academic work directly to the professional world, ensuring students gain skills that are not only theoretical but applicable in modern engineering practice.

Incorporating external agents into hands-on projects—whether through industry collaboration, expert evaluators, or real-world problem contexts—significantly enriches the learning experience. These external influences help students contextualize their theoretical knowledge and better understand the professional and practical implications of their work. For instance, Quandt, Mendes, & Przysiada (2019) used augmented reality to teach electrical circuits, involving external technology experts to provide students with state-of-the-art learning tools. This project model ensured that students engaged deeply with the material, while simultaneously being exposed to the latest industry trends and technologies.

The implementation of hands-on projects consistently demonstrates improvements in students' motivation, engagement, and academic performance. Projects that integrate real-world challenges and external agents, such as the electric vehicle project by Ariza & Olatunde-Aiyedun (2023) and the microgrid-based learning of Khan, Haque, Sachdeva, & Morgan (2022), create a dynamic learning environment where students are more invested in their work. As noted by Belcredi, Randall, Rattaro, & Belzarena (2020) in their SDR project, hands-on learning helps students identify their areas of strength within teamwork settings, which not only boosts confidence but enhances learning outcomes. In these environments, students report higher satisfaction and lower dropout rates, as noted in Azurza, Zubia, & Arruti (2023), where active learning reduced dropout rates from 45% to 5%.

Moreover, hands-on projects do more than improve technical skills; they foster essential soft skills, such as collaboration, communication, and leadership. Walentyński, Słota, & Szczygieł (2021) highlighted how interdisciplinary teams working on vibration control projects gained both technical knowledge and the ability to work effectively across disciplines. The focus on teamwork and communication is further emphasized in projects like Pinto, Nicola, & Mendonca (2019), where peer evaluation played a central role in the learning process, allowing students to refine their interpersonal and presentation skills—key components of professional success.

Despite the evident benefits, hands-on learning projects face certain challenges, particularly in terms of scalability and resource availability. Dofe & Kurwadkar (2021) point out that virtual PBL, while flexible, often lacks the tactile, immersive experiences that physical labs provide. This can dilute the learning process and limit the acquisition of practical skills. Similarly, Zhao & Niu (2023) note that while simulation-

based projects can effectively substitute for resource-intensive labs, they still fall short of offering the depth of learning that physical, hands-on projects provide.

More evidence is needed regarding the effectiveness of hybrid models that combine physical and virtual learning environments to maximize the benefits of both. Additionally, exploring more cost-effective ways to implement hands-on learning in resource-constrained environments is critical. Projects that leverage augmented reality, AI-based tools, or remote labs could offer solutions to these limitations, as seen in Quandt, Mendes, & Przysiada (2019) and Rajesh, Sivapragasam, & Dargar (2024), where simulation-based learning showed promise in enhancing student engagement and understanding.

Description of the project and main objectives to be achieved

The project is done in the course “Analysis of Electric Networks”, this course is taught in the fourth course of BSc. Industrial Technologies Engineering. It is an elective course within the Analysis of Electric Networks subject area and is offered in the Electricity Competency Module (MIELE) during the first semester of the 4th year. The course carries 6 ECTS credits, with 150 hours of student dedication, and consists of 69% theoretical content and 31% practical work. The course is taught in Spanish and is structured into large groups of up to 72 students for lectures, and smaller groups of 30 students for practical sessions. The same course is taught in BSc. Electrical Engineering, and BSc. Industrial Electronics Engineering. The subject focuses on the study of resonant circuits, two-port networks, asymmetrical tri-phase systems, and transients. The scope of this project is within the first two topics, as the author is involved only in teaching these parts.

In this course, a PBL activity is designed to actively engage students in the learning process through a hackathon format. The hereby proposed project aims to address the limitations found in literature by proposing a hybrid model that combines PBL with computer simulations. The core objective is to challenge students to develop a novel project related to a topic previously covered in class. This hands-on approach will allow students to not only reinforce their understanding of the material but also apply theoretical concepts to solve real-world engineering problems.

The hackathon will begin with guided tutoring sessions in class, where students will have the opportunity to receive mentorship and refine their project ideas. Afterward, students will work independently at home to complete their projects, applying both the knowledge gained in class and their own creativity. Finally, each group will present their completed project to the class, showcasing their results and demonstrating their problem-solving process.

Project objectives: General objectives. Justification of the interest and feasibility of the project

The primary objective of this project is to enhance active learning through the integration of a PBL hackathon into the course curriculum. This approach is designed to support traditional face-to-face teaching by engaging students in the hands-on application of theoretical concepts without compromising the central goals of the learning process, which will still be covered by traditional lessons. By encouraging students to develop novel projects, this initiative applies learning-to-learn principle, critical thinking, and real-world problem-solving skills, which are crucial in electrical engineering education.

The hackathon format specifically aligns with the general competencies outlined in the course syllabus, without jeopardizing the achievement of these learning objectives. The project directly supports basic engineering skills, as students will be tasked with designing, developing, and improving systems and processes through practical, hands-on activities. Besides, the applied nature of the hackathon promotes the integration of knowledge from various fields not only those already taught in the course. The final presentation of the project offers students the opportunity to practice their communication skills articulating their knowledge and conclusions in a clearly and effectively way, so they can bring to class new technologies and tools present in industrial engineering. The hackathon also cultivates creativity by pushing students to generate new ideas and think outside the box when developing solutions to the project challenges.

On a more technical level, the project is well-aligned with the specific competencies outlined in the syllabus, particularly in the context of the analysis and synthesis of electrical circuits and networks. The PBL activity requires students to apply these core concepts directly to the development of functioning models, reinforcing both their theoretical understanding and practical application skills.

Thus, the hackathon is designed to be fully compatible with the available resources, including lab facilities, simulation tools, and scheduled course time, as further presented in Section 2. In-class guided tutoring ensures that students have the necessary support throughout the process, and independent work outside of class allows them to further develop their projects. This structure ensures that students remain engaged without compromising the core learning objectives of the course.

METHOD

Description of the materials and methodology that will guide the learning process. Planned activities

The learning process for this course will be structured around a blend of traditional lectures, hands-on lab sessions, and a hackathon-style project. The traditional lectures will be delivered using PowerPoint presentations to convey theoretical concepts, while proofs and derivations will be demonstrated on the blackboard. In-class problem-solving exercises will support students in applying theoretical knowledge to practical examples.

The sections where the project is developed are organised as follows. The first section on resonance begins with Unit 1: Resonance in Series Circuits, covering the quality factor of real inductors and capacitors, properties at resonance frequency, variable frequency resonance, and bandwidth analysis. Unit 2: Resonance in Parallel Circuits explores real-world equivalent circuits of inductors and capacitors, the analysis of ideal parallel resonant circuits, and two-branch parallel resonance, also highlighting resonance frequency properties and bandwidth.

The second section delves into two-port networks, beginning with Unit 3: Matrix Representation of Two-Port Networks, where both passive and active networks are introduced. The topic covers open-circuit impedances, impedance and admittance matrices, transmission parameters, and hybrid “h” and “g” matrices. Unit 4: Two-Port Network Association discusses series, parallel, and cascade associations, focusing on their equivalent networks. Unit 5: Elementary Two-Port Networks explores symmetrical, reciprocal networks and various configurations such as L, inverted L, Π , T, and bridged X networks, along with Bartlett’s theorem and practical applications. Lastly, Unit 6: Image Parameters of Two-Port Networks covers image impedance, propagation constants, and their relationship to transmission and impedance parameters. It also addresses attenuation, phase constants, and transmission/insertion losses in symmetrical networks.

The capstone element of the course is a student-led hackathon. In this activity, students -individually or in small groups, depending on the number of enrolled students- will develop a novel project that demonstrates mastery of course concepts. Students will receive initial guidance during two sessions of 1.5 hours where project objectives and scope will be defined. Projects may involve simulation, lab demonstrations, or a combination of both, and students are encouraged to incorporate external resources, such as Arduino or similar tools, if they want to. The course will conclude with a presentation session, where students will showcase their projects and answer questions of the entire class.

Justification of the methodology from the perspective of its suitability for achieving the objectives

This methodology has been chosen for its balance between theoretical instruction, practical application, and creative exploration. Traditional lectures are essential for ensuring foundational knowledge, particularly in a course that involves complex theoretical subjects such as resonance and two-port networks. By complementing these lectures with laboratory sessions and the hackathon project, students are given the opportunity to directly apply their knowledge in a controlled environment, which is one of the major difficulties encountered in the past in the context of Engineering Degrees. In addition, students will be requested to hand-in 7 different exercises covering the materials of each unit, promoting continuous learning.

The inclusion of the hackathon element is critical for encouraging engagement with the subject. Research has shown that active learning methods, particularly those that involve student-generated projects, improve not only knowledge retention but also motivation and problem-solving skills (Ariza & Olatunde-Aiyedun, 2023; Khan, Haque, Sachdeva, & Morgan, 2022). The guided tutoring and peer presentations will foster a collaborative environment, promoting soft skills like communication and teamwork that are essential in engineering education (Serrano et al., 2023).

Appropriateness of the materials and methodology for each type of activity

The traditional lecture format is suitable for delivering core theoretical content that students need to understand the underlying principles of resonance and two-port networks. The use of PowerPoint presentations and blackboard demonstrations allows for clear, structured instruction that is digestible in the classroom context. Students need these sessions to fully comprehend the materials and apply them in the given homework.

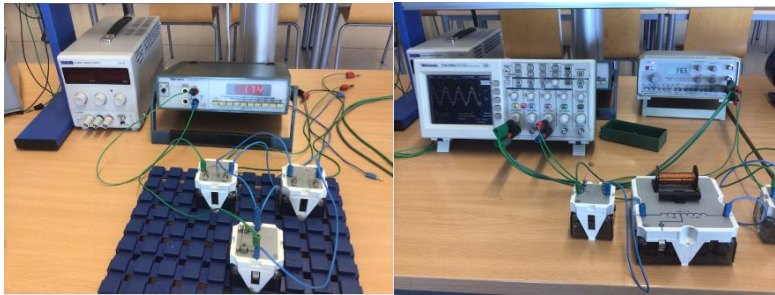
The laboratory sessions are tailored for practical, hands-on application of the theory. Providing students with tasks in advance encourages self-directed learning and ensures they arrive prepared to maximize their lab time. The hands-on nature of these sessions is crucial for developing the technical skills required in electrical engineering, such as circuit assembly, measurement, and troubleshooting.

The hackathon format is an innovative approach to encourage students to integrate what they have learned into a creative, student-driven project. This activity promotes independent thinking and active problem-solving, both of which are key to mastering complex engineering concepts (Flores & Villicaña, 2018). It also provides an opportunity for students to explore areas of personal interest, enhancing engagement.

Available resources (ICT, Centre, Department, others...) and their suitability for the project

The Department of Electrical Engineering at the University of Málaga provides access to fully equipped laboratories for the practical components of the course. These labs contain necessary hardware, including oscilloscopes, signal generators, and circuit assembly materials as depicted in Figure 1. Additionally, students will have access to simulation software (e.g., MATLAB Simulink, PSpice) in the computer rooms enabled by the School of Industrial Engineering, which can be utilized during the hackathon for project development, or they could use any other open software that they could find on the internet.

Figure 1. Material necessary for completing the laboratory sessions



The university's Virtual Campus platform will be employed for the distribution of assignments and resources, as well as for the submission of exercises, ensuring direct communication and assessment management. The availability of these technological tools aligns with the course objectives, enabling students to transition seamlessly between theoretical learning and practical application.

Indicators and marking system

The course grading will be structured as follows:

Assignments on Virtual Campus (10%). Students will be evaluated on their ability to complete theoretical and practical exercises throughout the course. The total grade in this section will be obtained as the arithmetic mean of the 7 different scheduled homework tasks.

Lab Performance (20%). During lab sessions, students will be assessed based on their proficiency in assembling circuits, conducting experiments, and accurately reporting their findings on the same sessions. Students will be given with a dossier with the required activities to be performed during the two lab sessions, they work them at home and then, report to the professor the different experiment results during the time available in laboratory directly, answering any question that the

teacher could question during the process. In this way, students are trained in competences such as communicate technical conclusion in a clear and concise way in front of other technical peers.

Hackathon Project (15%). Students will be graded on the originality, technical execution, and clarity of their project presentations. Both the implementation of the project and its presentation will be considered.

Final Exam (55%). An exam will cover all theoretical and practical aspects of the course, ensuring that students can demonstrate their understanding of both the lecture content and lab experiences. The exam will have two parts, covering both blocks.

Scheduling of the project

The course is organized over seven weeks, i.e. half of the semester available, with a mix of traditional lectures, lab sessions, and the final hackathon (ElectroHack) project. Below is the detailed course schedule, including session contents, homework assignments, and deadlines:

Table 1. Course schedule with session contents

Week	Session	Duration	Session Contents	Homework	Due Date	Room
1	1	1.5 h	U1 - Resonance in Series Circuits			Classroom
1	2	1.5 h	U1 - Resonance in Series Circuits			Classroom
1	3	1.5 h	U1 - Resonance in Series Circuits	RES-I	S6	Classroom
2	4	1.5 h	U2 - Resonance in Parallel Circuits			Classroom
2	5	1.5 h	U2 - Resonance in Parallel Circuits			Classroom
2	6	1.5 h	U2 - Resonance in Parallel Circuits	RES-II	S9	Classroom
3	7	1.5 h	U3 - Matrix Representation of Two-Port Networks			Classroom
3	8	1.5 h	U3 - Matrix Representation of Two-Port Networks			Classroom
3	9	1.5 h	U3 - Matrix Representation of Two-Port Networks	TPN-I	S12	Classroom
4	10	1.5 h	U4 - Two-Port Networks Association			Classroom
4	11	1.5 h	U4 - Two-Port Networks Association	TPN-II	S14	Classroom
4	12	1.5 h	U5 -Elementary Two-Port Networks			Classroom
5	13	1.5 h	U5 -Elementary Two-Port Networks			Classroom
5	14	1.5 h	U5 -Elementary Two-Port Networks	TPN-III	S17	Classroom
5	15	1.5 h	U6 - Image Parameters of Two-Port Networks	TPN-IV	S18	Classroom
6	16	1.5 h	Lab 1: Resonance			Lab
6	17	1.5 h	Lab 2: Two-Port Networks			Lab
6	18	1.5 h	ElectroHack - Guided class			Lab
7	19	1.5 h	ElectroHack - Guided class			Lab
7	20	1.5 h	ElectroHack - Presentations			Lab

Weeks 1-5. Theoretical instruction covering resonance and two-port networks. Homework assignments (RES-I, RES-II, TPN-I, TPN-II, TPN-III, and TPN-IV) are designed to reinforce understanding and are due after finishing each unit. Students are given 1 week to complete them, thus being completed before ElectroHack starts.

Week 6. Lab sessions for practical application of concepts. During these sessions, students go over a set of predetermined practical circuits given in a dossier a week in advance. They are encouraged to work on these dossiers at home before the laboratory sessions begin. In this week students receive the first guided class regarding the ElectroHack.

Week 7. ElectroHack continues with the second guided class, culminating in final presentations where students demonstrate their projects.

This schedule ensures a structured balance between theory, practice, and creative project development, meeting the 30 h of teaching required by the syllabus. This timeline provides enough time to cover both hand-in exercises and laboratory activities, promoting students to follow the course as it being taught. All class durations are 1.5 h.

EXPECTED RESULTS

Aspects to be evaluated once the project is completed

The impact that the project has on students will be evaluated considering the following facets:

Knowledge Retention and Concept Mastery. Through continuous assessments, lab exercises, and final exams, students' understanding of core concepts like resonance in circuits and two-port networks will be evaluated. The focus will be on long-term retention and the depth of conceptual mastery, comparing homework, lab performance, and exam results compared to previous years where the project has not been done.

Practical Application of Engineering Skills. The hackathon and lab sessions will evaluate the practical application of theoretical concepts. Students' abilities in building, troubleshooting, and explaining circuit designs will be assessed, with special attention to how well they can translate theory into practice. In addition, the students will be required to conduct a self-assessment of acquired skills to understand their view on this.

Engagement, and Motivation. The hackathon format and lab-based activities will be evaluated based on student engagement, with surveys and attendance records serving as indicators.

Description of the evaluations

To evaluate the impact of the project on student learning and engagement, a combination of qualitative and quantitative assessment methods will be employed:

Hackathon Project Evaluation

The hackathon project will be assessed based on i) technical accuracy, ii) innovation, iii) application of theoretical knowledge, and iv) clarity of the presentation. A rubric system will be used to score these dimensions.

Student Feedback and Engagement

Surveys and Feedback Forms. Students will be asked to complete pre- and post-project surveys to capture their perception of the hackathon experience, their engagement levels, and whether the project improved their understanding of key concepts. Qualitative feedback will provide insights into the overall impact of the project on their learning experience.

Attendance and Participation Metrics. Attendance and active participation during classroom, laboratory and project sessions will be recorded as an indicator of engagement. Higher rates of participation compared to previous, more traditional activities will suggest a positive shift in student involvement.

Knowledge and Skill Acquisition

Lab Session Outcomes. Lab performance will be evaluated during the practical sessions, where students will be required to demonstrate their ability to assemble circuits, conduct measurements, and report findings. These outcomes will help assess the effectiveness of lab activities in reinforcing theoretical knowledge.

Final Exam and Homework Results. The final exam and the homework assignments will be used to evaluate how well students have retained core concepts and applied them effectively. Comparisons between exam performance before and after the hackathon will provide insights into the impact of the hands-on learning experience on long-term knowledge retention.

CONCLUSION

The implementation of the ElectroHack project in the “Analysis of Electrical Networks” course is expected to significantly enhance student engagement and learning outcomes by integrating hands-on learning through a hackathon format. This approach will directly involve up to 72 undergraduate students in Engineering at the University of Málaga, focusing on two key areas: resonance circuits and two-port networks. By challenging students to apply theoretical concepts in a practical and innovative manner, the project aims to bridge the gap between theoretical knowledge and real-world engineering applications.

The project’s impact is expected to extend beyond the immediate scope of this course, since Hackathon frameworks are easily transferable among courses within Engineering degrees curriculum, such as power electronics or control systems, where

active, hands-on learning could enhance concept mastery. Additionally, the ElectroHack project offers potential for broader adoption across different departments, since this format can be exported in inter-departmental subjects where two or more department shares sessions over a course.

Moreover, the ElectroHack model, with its emphasis on innovation and external resources like simulations and hardware, offers a scalable approach that could engage more students and faculty across disciplines. As the project demonstrates successful outcomes in terms of motivation, knowledge retention, and practical skills development, it could serve as a framework for enhancing teaching practices across other engineering qualifications at the University of Málaga and beyond.

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