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Strategies for effective CBL implementation: from company selection to course evaluation

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In this study, we explore the key factors that educators must consider when designing challenges based on the Challenge-Based Learning (CBL) strategy, where the industrial sector serves as the educational partner. Building on our proposed definition of the CBL technique, we outline a methodology complete with practical suggestions to effectively tackle the challenges encountered during the strategy's implementation. The recommended steps involve choosing a training partner, establishing the company's role in the challenge, taking economic factors into account, and pinpointing crucial milestones in the course development, which includes recognizing the partner's involvement and significance in the course evaluation. Our proposal draws from the authors' experiences in applying this methodology within the context of an Industrial Automation course.

KEYWORDS

academia-industry collaboration, challenge-based learning, professional education, educational innovation, higher education, Rockwell Automation, GENERAC

1 Introduction

Without a doubt, the COVID-19 pandemic left great consequences in the world, and despite great efforts, the economy is recovering very slowly. In the area of education, the damage was not minor. According to the International Monetary Fund (2022) report, between 2020 and 2021 school interruptions affected approximately 1.6 billion students, with those countries with poor academic results since before the pandemic being most affected. Several studies have shown that this isolation produced, among many other complications, an educational gap, and this gap was greater if the school closed for a longer period (Jakubowski et al., 2024). There are multiple factors that influence the decrease in academic performance, for example, that the teaching-learning process during the pandemic was less cognitively demanding (Gasteiger et al., 2023).

Therefore, it is not enough to merely return to the classrooms today; we must seek or resume strategies that help recover lost education time. Based on this premise, in 2019 our institution made a significant change in study plans, transitioning from a traditional model to one centered around competencies and challenges. The primary tool for this approach is the Challenge Based Learning (CBL) technique, where students apply their knowledge to solve real-world problems. This is the objective pursued in the Industrial Automation subject: enrolled students must solve real problems applied to the industrial field, which is why the support of leading companies in this industrial sector has been sought.

However, the implementation of this teaching-learning strategy presents challenges that both teachers and students must overcome. For instance, Membrillo-Hernández et al. (2019) observed that students face difficulties due to their unfamiliarity with concepts such as openness, independence, and personal responsibility. To succeed in CBL, students need to be proactive and committed to competency development. Overcoming initial resistance, such as making individual decisions or tackling unresolved challenges, is crucial for achieving good performance.

Regarding teachers, the CBL model requires a transition from traditional lecture-based teaching to a more facilitative and mediating approach. However, research has primarily focused on teachers' expected attitudes and roles, without delving deeply into their individual experiences. Sukackė et al. (2022) identify that specific results from surveys, questionnaires, or interviews targeting teachers have not been found. Therefore, the aim of this study is to address this gap in the literature by documenting teachers' experiences in implementing this learning strategy.

In this work, important points that the teacher faced when developing this type of activities with the industry are presented and analyzed. Elements from the search and selection of companies to the implementation of the challenge, in general, the problems faced and the way in which they were resolved. Likewise, the impact on the perception of students and company engineers regarding this teaching methodology is presented.

While students gain diverse and valuable knowledge and skills through these types of projects, it is equally important to highlight the teacher's learning experience when implementing this didactic technique. Such activities push educators out of their comfort zone, as each project presents unique challenges. The insights gained from tackling this work are what we aim to convey in this paper.

It is hoped that this work will serve as a guide for educators wishing to implement these teaching methodologies with industrial partners. Without a doubt, this teaching strategy helps to better prepare students by supplying them with the skills and knowledge required in today's industrial world.

2 Review of related literature

In most Engineering programs there is a subject located in the last semester of the study plans called the end-of-degree project, stay or professional internships. The objective of this subject is for students to develop a project or carry out professional practices that allow them to apply the knowledge acquired (Sanchis et al., 2024). Recent works have proposed modifying this format by incorporating elements that improve the learning experience of students by making research proposals and evaluating theoretical understanding through oral defenses and the creative talent of students (Rana et al., 2024). Hojas and Del Toro (2021) argue that a final degree project should be a practical application that offers a real solution to a societal problem. Therefore, they propose that these projects be multidisciplinary, allowing different specialties to collaborate in designing various alternatives and selecting the one that best fits the problem's characteristics.

While final degree projects are crucial for knowledge development, they are typically applied exclusively at the end of the degree. However, waiting until the end of the program to apply knowledge is not the only option. Students do not need to wait until the final stages of their studies to apply what they have learned. They can also develop projects where they apply their knowledge before reaching the final stage of their studies. Early application of knowledge during the degree is essential—it allows students to consolidate their learning, develop practical skills, and understand the relevance of their education. Furthermore, by applying theory to real-world projects, creativity and problem-solving abilities are encouraged. Ultimately, this experience contributes to better student preparation and is one of the fundamental pillars of challenge-based learning (Höffken and Lazendic-Galloway, 2024).

In summary, if the student applies what they have learned in the early semesters of their degree, they will gain several benefits. This will help solidify theory, develop practical skills, and enhance their understanding of the relevance of their education. Additionally, engaging in real-world projects nurtures creativity and problem-solving abilities, better equipping them for the professional world. To put it simply, starting projects early in their academic journey enriches their overall experience (Jiménez-Gaona and Vivanco-Galván, 2024).

On the other hand, it is undeniable that developing projects with the industry allows students to develop the skills and competencies necessary to address and generate innovative solutions to real problems. In the review of the literature, different investigations develop a plan to improve collaboration between the University-Industry. Ahmed et al. (2022) proposes a model that includes processes, methods or approaches, and tools. This proposal serves as a map showing the steps that help establish collaboration between academia and industry by implementing processes effectively. Broadbent and McCann, in 2016, proposed a guide designed to augment strategic guidance and case studies with practical, actionable suggestions for universities, industries, and professional engineering institutions. This guide aims to assist these entities in achieving and reaping the benefits of effective industrial engagement. Adopting a grounded theory approach, Bürger and Gonçalves (2021) demonstrated that university-industry interaction is influenced by several factors, such as networking, legal support, facilitating agents, and management practices. Strengthening the triple helix, greater legal security and promoting open innovation are other factors identified to improve University-Industry relations. Srinivas and Varaprasad (2024) carries out an analysis where the central element is collaboration, which promotes elements such as innovation, knowledge exchange and interdisciplinary advances. Collaboration refers to the practice of bringing together scholars, researchers, and academic experts from different disciplines to work collectively on research projects, educational programs, or problem-solving initiatives.

In the examined studies by Ahmed et al. (2022), Broadbent and McCann (2016), and Bürger and Gonçalves (2021), each author presents a guide of best practices for enhancing University-Industry Collaboration effectiveness, drawing on their experiences and/or consultations with professionals and academic researchers. They concur that this partnership offers invaluable experiences to everyone involved.

2.1 Review challenge based learning (CBL) technique

Although the exact origins of the CBL technique remain uncertain, Perna et al. (2023) have explored the beginnings of this learning strategy. They identify the Apple Classrooms of Tomorrow—Today (2008) project as the source with the highest number of citations. Perna's work builds upon existing literature reviews and identifies additional publications to offer a deeper and more comprehensive understanding of CBL. Nichols and Cator (2008), mention that the CBL effort is part of a larger collaborative project initiated with the ACOT2 project. They establish that CBL involves collaborative experiences where teachers and students work together to explore compelling issues, propose solutions to real-world problems, and act.

According to Leijon et al. (2022), CBL is a pedagogical approach that actively engages students by integrating traditional learning courses with real-world challenges. These challenges require innovative, creative, and often multidisciplinary interventions for resolution. Students, external stakeholders, and training partners or external actors (from industry or the public sector) collaborate to address these challenges. The strategy exposes students and professors to real-world problems that need solving. In this context, acquired knowledge is tested, and students develop the skills necessary to navigate the labor market and meet the demands of today's society (Membrillo-Hernández et al., 2023).

Doulougeri et al. (2024), emphasize that CBL builds upon the strengths of other active learning pedagogies, encouraging students to learn autonomously and collaboratively within specific contexts. It aims to develop students' disciplinary and cross-cutting competencies by involving them in solving challenges. The novelty of the strategy lies in the diverse types of challenges that students tackle, varying in complexity, context, and global relevance, making CBL a dynamic and impactful learning experience (Doulougeri et al., 2021).

According to Sukackė et al. (2022), the role of teachers has undergone a significant transformation. Among their new responsibilities is establishing connections with industry partners who can actively participate in students' learning processes. Additionally, teachers collaborate with these partners to organize student challenges, ensuring adequate time for achieving learning objectives and accessing necessary resources. Another crucial aspect is guiding students throughout the challenge, providing both individual and group support, overseeing sessions, and facilitating discussions when student teams collaborate. In all cases, teachers analyze student progress to adjust pedagogical strategies and modify resources as needed (ObservatorioIFE, 2023).

Based on the cited references and the work conducted, we define *Challenge-Based Learning (CBL) as a pedagogical approach that actively engages students in real-world problem situations within an industrial context. We refer to these situations as "challenges," which must be specific and achievable. It is essential for students to actively participate throughout the process, researching both the problem and potential solutions. The teacher's role is crucial, as they must find an industrial partner willing to support course development, contributing time, effort, and even financial resources, all with the sole aim of maximizing student learning.*

In summary, CBL is a dynamic pedagogical approach that immerses students in authentic real-world problem scenarios within an industrial context. Active student participation is crucial for the success of this methodology.

3 Methodological procedure

The subject in which the methodology was applied is Industrial Automation. This intermediate-level course in mechatronics engineering, located in the sixth semester of the curriculum, equips students to integrate and implement automation solutions in industrial processes using various industrial networks. Key networking concepts, including Interface Actuator-Sensor,[1] Profibus,[2] Profinet [3]Ethernet/IP (EtherNet/IP™ | ODVA Technologies | Industrial Automation, 2024), and OPC-UA,[4] among other protocols, are explored. The professor of the course has extensive experience working in these areas, with more than 20 years in the educational field and providing industrial training, so he knows the topics.

The course has a duration of 120 h spread over 10 weeks, with 80 h dedicated to covering the course syllabus and 40 h for challenge development. By this point in their program, students have established a strong foundation in mechanics, electronics, and computer science. They have previously completed courses covering basic programming for Programmable Logic Controllers (PLC) and acquired knowledge in sensors, actuators, control systems, and microcontrollers.

The theoretical course is complemented with practical exercises in the laboratory, where six practices are implemented:

- Review of PLC programming fundamentals.
- Interface Actuator-Sensor (AS-i) communication protocol.
- Profibus DP communication protocol.
- Profinet communication protocol.
- Ethernet IP communication protocol.
- OPC-UA communication protocol.

The course assessment consists of 40% based on challenge resolution and 60% on theoretical evaluation. Challenges are assessed at two points: during week 5 and week 10. The theoretical evaluation includes two individual exams, two quick exams, and the submission of practice reports. The challenge is evaluated by both the teacher and the industrial partner, while the instructor ponders the theoretical evaluation of the course.

It is crucial to emphasize that the course strictly adheres to the syllabus, ensuring comprehensive coverage. Furthermore, the challenge assumes a pivotal role in the curriculum, allowing students to apply knowledge not only from the current course but also from previous ones. Consequently, selecting an appropriate challenge becomes essential to align with the course syllabus.

The Industrial Automation course with the new teaching-learning approach based on CBL has had the participation of four groups of students. Specifically, during the period from February to June 2022, two groups participated, and during the period from February to June 2023 another two groups, with 18 students in each group.

The first group of students (February–June 2022) collaborated with GENERAC, a leading energy technology firm specializing in advanced electrical network software solutions, backup systems, and primary energy for residential and industrial use. The second group (February–June 2023) collaborated with Rockwell Automation a global leader in automation, industrial control, and communications.

These topics were chosen because they directly relate to industrial communication networks. Both projects involve control and

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[1] https://www.as-interface.net/

[2] https://www.profibus.com/

[3] https://us.profinet.com/

[4] https://opcfoundation.org/

communication systems within industrial environments. In the first case, the focus is on communication via the Controller Area Network (CAN) bus protocol between controllers and machinery (Buscemi et al., 2023). In the second case, the proportional-integral-derivative (PID) controller—also known as a three-term controller—is adjusted in industrial devices to control variables such as motor speed. These concepts play a fundamental role in the context of industrial communication networks, where efficiency, reliability, and safety are critical.

In the following subsections, the key elements identified by the professor when implementing the learning strategy are described. These elements are summarized in steps that outline their methodological proposal.

3.1 Search for training partner

As mentioned earlier, our institution's curricular reform emphasizes the application of the CBL technique and aims to foster collaboration with industry partners. In this context, industry partners serve as external actors or training partners. This collaboration provides students with valuable experience in addressing real-world industrial problems, preparing them for their professional careers. Therefore, the first step in implementing the CBL technique is to search for and select the industrial partner.

According to Bürger and Gonçalves (2021), contact with the company can be established through colleagues who have executed successful projects with companies or through students currently doing internships in these companies. Additionally, it is possible that some students have relatives or friends in the industrial field who can provide support in this process. Identification of stakeholders and the problem to be addressed are intertwined and they are not sequential and can occur randomly (Awasthy et al., 2020).

When choosing companies, it is advisable to select those related to the subject of the course. Additionally, consider identifying companies located near the university for easier visits, interviews, and consultations. GENERAC has its Technology Center near the campus, allowing for smoother discussions to establish the challenge and receive advice from their experts, always respecting established schedules. Conversely, Rockwell Automation offices are distant from the campus, necessitating the use of virtual tools for guidance. Given that students are emerging from the pandemic period, there was a preference for in-person interactions with experts, as we have observed that face-to-face advising has a greater impact on students.

Finding companies willing to engage in these types of activities can be challenging. Post-pandemic, only a few companies have the resources or desire to support universities in developing such initiatives. Allocating budgets to these projects often does not yield tangible benefits for them. Additionally, they must consider costs like assigning personnel to coordinate with faculty and fine-tune the challenge proposal and related activities. This includes the time personnel will dedicate to advising and evaluating the challenge, as well as potential use of the company's own software and hardware.

On the other hand, some companies may propose projects that are not aligned with the course content, or they may present excellent proposals without a genuine commitment to supporting this learning strategy. In such cases, it is advisable to either avoid or reconsider collaboration with them. It is also crucial to verify that proposed projects align with the course's objectives.

Colleagues who had previously worked on projects with these companies recommended and introduced them for this project. The companies were informed about the CBL model and expressed interest in participating.

3.2 Project definition

As mentioned earlier, once you establish contact with the company, the next step is to design or structure the challenge, ensuring it aligns with the course. This is where the professor's experience comes into play to redefine the problem. To achieve this, it is essential to initiate meetings to define the specific problem that will be presented to the students. Additionally, a clear explanation of the company's role as a training partner in student learning should be provided, along with expectations for active contribution to initiate the collaboration.

In the CBL learning technique, students propose a solution to the challenge by researching, analyzing, proposing, and implementing solutions. Therefore, the following points must be clear and established in the first meeting with the company:

- The teacher will not solve the problem.
- The challenge is not a consulting project.
- The problem will be solved by the students themselves, so due to their experience they may not get the solution they are looking for.

What will the company get?

- Identify students for recruitment.
- Brainstorm to explore a possible solution.
- Train students in the use of their equipment. It is better that they receive prior training at school before coming to the company.
- Positioning of your brand. Students will graduate with your products in mind.

On the other hand, company should appoint a responsible engineer who will maintain ongoing communication with the teacher throughout the course. The assigned engineer must recognize the significance of their role within the learning strategy. They actively contribute to formulating the proposal and implementing the necessary adjustments for the challenge. It is important to note that this activity takes place before the course begins.

Although the challenge will be solved by the students, it is necessary for the teacher to know and understand the issues required to address and solve the problem. At many points in the project, the student will doubt the proposed solution. Therefore, feedback from both the teacher and the company engineer plays a fundamental role in ensuring project success. The teacher's expertise is vital in assessing whether the challenge aligns with the knowledge students will acquire during the course.

3.3 Course objectives vs. challenge

Another crucial aspect is ensuring that the challenge or project aligns with the course objectives. Sometimes, companies propose projects that students can technically solve easily based on their acquired knowledge. However, these projects may not cover the specific topics of the course, and ethically, they should not be considered. Conversely, there are cases where the project scope needs to be limited. Before selecting a project, it is essential to review the course objectives, intent, and learning outcomes. While an ideal project would cover 100% of the course topics, such projects are rare in practice.

The above is decisive for a meaningful learning experience.

1. Alignment with course objectives:
   - Ensure that the project directly relates to the learning goals of the course.
   - Review the syllabus and objectives to identify key topics and skills students are expected to master.
2. Ethical considerations:
   - Avoid projects that are technically simple but irrelevant to the course content.
   - Ethically, students should engage in tasks that contribute to their learning and skill development.
3. Balancing complexity:
   - Strive for a project that challenges students without overwhelming them.
   - Avoid overly complex projects that hinder learning or exceed course expectations.
4. Ideal vs. realistic:
   - While an ideal project would cover 100% of course topics, real-world constraints often limit this.
   - Prioritize essential topics and focus on meaningful application.

A well-designed project enhances student understanding and prepares them for real-world scenarios.

3.4 Economic resources, hardware, and software

The availability of equipment and software is crucial for meeting the challenge. It is worth checking the university laboratories for available devices and exploring the possibility of obtaining equipment from partner companies.

1. School equipment:
   - It is essential to determine whether the school already possesses the necessary devices and software. Does the school have these devices to solve the challenge?
   - If so, it is important to assess how accessible they are to students. How many devices are available?
2. Company support:
   - In some cases, companies may provide equipment or software for educational purposes. Will the company provide it?
   - If the company is involved in the project, it is worth discussing their level of support and any resources they can offer.

It is highly desirable that student costs be reduced to electronic components, supplies, and personal equipment. In addition, if the company has a factory or learning center, it is desirable to visit. This further enriches the learning experience, as students see where the exercise can be applied. Visiting a company's factory or learning center can significantly enhance the learning experience for students. In this case, the University must cover the transportation costs to take the group on the visit. Other costs that impact the development of the challenge are consumables, in addition the University must provide the electronics and machine-tool laboratories, as well as the support of the technical staff for the construction of the required elements.

It is also necessary to consider the visits that the teacher makes to companies. Although the vast majority can be done virtually, it is desirable that at least one or two visits are made face-to-face to reaffirm the commitment that is being acquired in this learning process. The University must consider these costs in the budget.

Clear communication is the cornerstone of a successful collaboration. When all parties involved engage in an open dialogue, the results are positive (Awasthy et al., 2020), (Srinivas and Varaprasad, 2024).

3.5 Key events in the challenge

In the course development process, there are key moments that must be considered for the success of the CBL strategy. These can be summarized as follows:

- The presentation of the challenge by the company's engineers is crucial. This presentation must be delivered in person on the first day of classes, or alternatively, during the first week of classes. During this initial presentation, an overview of the company is provided, the challenge to be addressed is introduced, deliverables are outlined, and the evaluation methodology is established. Effective communication by the engineers is essential, ensuring that participants fully understand the scope of the challenge and the company's expectations. This initial presentation can detonate enthusiasm and motivation among students, contributing to the project's success.
- Course feedback moments. During the course, the teacher should assess the project's progress. Additionally, it is advisable for the training partner to conduct at least two interim evaluations of the project's advancement. These evaluations can take place either face-to-face or online.
- Expert Talks and Workshops delivered by professionals from the company. It is highly desirable that the company actively contributes by organizing talks on topics directly relevant to the challenge. This not only demonstrates the company's commitment as a training partner for the course but also enriches the learning experience for students.
- Final evaluation. It serves as the culmination of the project, and it is mandatory for it to be conducted face-to-face. During this evaluation, students must showcase a functional prototype or experiment related to their proposed solution for the challenge. Through a structured and convincing oral exam, they demonstrate the adequacy and effectiveness of their solution. This assessment ensures that students have successfully applied their knowledge and skills to address the challenge.

When planning a challenge, it is crucial to balance the hours allocated for the challenge itself and those devoted to developing the syllabus. It is essential to ensure that the time spent on the activities mentioned above aligns with the challenge schedule. Effective organization is key, as an inadequately designed challenge can inadvertently consume more time, potentially detracting from course development efforts. In the context of challenge activities, there are occasions when certain elements must be sacrificed. For instance, visits or talks may need to be foregone to prioritize advancing the agenda. Conversely, some topics may not receive an in-depth review to facilitate progress in the challenge. Achieving the right balance requires the teacher's experience in managing such activities.

4 Methodology applied

In this chapter, we delve deeper into the steps described in the Methodological Procedure. We address the proposed challenges, the management of economic resources, the handling of hardware and software used in the projects, as well as the problems faced during project development.

This work is grounded in the experience and knowledge acquired from teaching these courses. It is worth noting that, although the methodology has been applied in other courses as well, our exclusive focus remains on Industrial Automation.

The choice of the CBL methodology is based on its ability to actively engage students in solving real-world problems in collaboration with industry. This approach not only enhances students' technical competencies but also develops soft skills such as communication and teamwork. However, this approach carries certain risks, such as dependence on the availability and commitment of industrial partners. To mitigate these risks, clear agreements were established with the participating companies, and continuous support was provided to both students and industrial partners.

4.1 GENERAC proposal

As mentioned earlier, the first group of students (February–June 2022) collaborated with GENERAC. This company uses dedicated controllers called Deep-Sea (DSEGenset | Deep Sea Electronics, 2024) to communicate with a gas engine and obtain data such as revolutions per minute (RPM), pressure, temperature, and more. These data are displayed on the Deep-Sea. Additionally, the CAN bus communication protocol is employed for data exchange between both devices.

The issue raised by the company is that once they design a control algorithm in the dedicated Deep-Sea controller, they need to connect it to an actual motor for testing. While the controller is programmed in their offices, testing requires them to travel to the location of the motor or, in some cases, they lack physical access to one. The proposal involves designing a "dummy" motor that deceives the controller, simulating the presence of a real motor.

Initially, a specific microcontroller proposed by the company was required to simulate the "dummy" engine. However, neither the professor nor the students were familiar with that device. Studying a new processor was beyond the scope of the course curriculum, and the allotted time for the challenge would not suffice. Additionally, it was not an area of expertise for the professor, so supporting the challenge's development was challenging. Consequently, the problem was redefined, and the decision was made to use an Arduino microcontroller—a platform already familiar to the students. The engineers at the company accepted the new proposal because they wanted to determine if communication with the dummy motor was feasible. The project's original objective remained intact: studying the Modbus protocol and data exchange between the Deep-Sea controller and the dummy motor.

Since there is no Modbus equipment in the laboratories, the professor asked the university department to acquire equipment that would allow the Arduino microcontroller to have communication via Modbus. The company provided Deep-Sea controllers for final testing, as well as training for the use of the equipment.

In the CBL technique, students must solve the challenge by designing the necessary phases to achieve their objectives. However, the professor specified project milestones to align with the company's deliverables. Forming teams of four members, as a first step, they were asked to establish Modbus communication between two Arduino microcontrollers. In a second step, two teams collaborated to establish communication between four devices. Finally, they were tasked with establishing communication between the microcontroller and the Deep-Sea controller.

During the middle of the course, a review was carried out where students communicated their microcontrollers via Modbus. In the final review, communication was established with the controller of Deep-Sea, which allowed the exchange of data requested by the company. Both reviews were face to face. In terms of orientation, the company organized two video conferences with experts in its programming modules. In these meetings, the programming codes were reviewed by team and suggestions for improvement were given. Additionally, due to their proximity, students had the opportunity to directly consult the Deep-Sea controller expert to address any doubts, all while adhering to the schedules established by the company.

The final presentation and deliverables including the white paper and manuals describing the Modbus communication process between the two devices were written in English at the request of the company (the native language is Spanish). A brief report on the results of this work is shown in Varela (2022).

4.2 Rockwell Automation proposal

The second group of students (February–June 2022) collaborated with Rockwell Automation a global leader in automation, industrial control, and communications. For this project, we utilized Rockwell Automation branded equipment, including the Compact Logix Programmable Logic Controller (PLC) and the PowerFlex 525 frequency converter. Additionally, AC motors were employed—commonly used in industry for controlling conveyors, compressors, fans, and pumps. Both the PLC and PowerFlex devices feature embedded Proportional + Integral + Derivative (PID) control loops. A PID controller is an algorithm used in engineering and automation to automatically adjust control system parameters. It helps regulate variables such as speed, temperature, or pressure in industrial processes. In our project, we tuned the PID regulators in both devices to regulate the angular speed of an alternating current motor and compared their performance. The resulting data was displayed on a human-machine interface (HMI) for better interpretation.

The Rockwell Automation initial proposal aimed to update their user manuals, requiring the exclusive use of their branded equipment. Fortunately, the laboratory had some of these branded devices, although not all that were requested. Consequently, we redefined the proposal to align with the available equipment.

Due to limitations, the revised proposal was limited to an alternating current motor, a PowerFlex 525 controller, and a PLC for each workstation. The original proposal initially included a PowerFlex 4 M. However, due to budget constraints within the department, it was necessary to revise the proposal and adapt it to the existing equipment available in the laboratory.

Throughout the course, Rockwell Automation organized three conferences with its expert engineers in areas related to the challenge: two via video conferences and one in person. Additionally, a visit to their Technology Development Center was arranged, where they showcased industrial applications using the equipment employed in the challenge. The visit and conferences provided them with a broader perspective on the significance of solving their challenge by demonstrating how it is being implemented in the industry.

Overall, the evaluation process resembled that conducted with GENERAC including both an intermediate evaluation conducted via video conference and a final evaluation carried out in person. During the final presentation, the teams demonstrated the functionality of the experimental platform. They explained the programming code and showcased the Human-Machine Interface (HMI) design, which facilitated engine parameter control and monitoring.

4.3 General discussion and comments

There is a strong commitment between the company and the professor in this type of project. The company contributes resources by assigning an engineer to work in tandem with the professor for planning, monitoring, and evaluation activities. Additionally, it assigns other professionals for conferences and, as in the case of GENERAC lends industrial equipment to complete the challenge. With this moral commitment, the course had to be adapted to ensure satisfactory results in the challenges.

Among the factors that forced the modification of the curriculum is the equipment. The laboratory comprises four workstations equipped with industrial software and hardware. Considering that classes were conducted for two groups, coordination was essential for conducting experiments at these workstations. Each group was further divided into four teams, with each team assigned to a specific workstation. This assignment was non-negotiable, as it helped identify who was working at each station.

In the case of the GENERAC they provided us with four Deep-Sea controllers, one for each workstation. Strict control was maintained over equipment loans, and they were granted only after completing the training course on the use of this controller. The university acquired the microcontrollers and Modbus communication modules due to their cost-effectiveness. On the other hand, regarding the Rockwell Automation challenge, the necessary equipment is available at each workstation. However, any misuse or equipment breakdown could jeopardize project delivery due to the limited availability of additional equipment.

The laboratory administration has an online reservation system where students can reserve workstations. However, this system does not differentiate whether the reserving students belong to the same team. As a result, some teams monopolized workstations throughout the day, leaving no opportunity for the other group of students. To address this, immediate adjustments were made by balancing the reservation times for each team. Despite these efforts, the high demand for equipment led the instructor to eliminate Practice 6 to adjust project delivery times.

Another factor that influenced the change in the course structure is the varying complexity of challenges. In the case of the GENERAC challenge, the Modbus communication protocol was unfamiliar, requiring students to learn and understand it anew. They had to grasp new concepts and apply them effectively. Regarding the Rockwell Automation challenge, its main advantage lies in the fact that PLC programming is part of the course curriculum. Additionally, the study of PID controllers is covered in the Control Theory subject, which precedes this course in the curriculum. The students were already familiar with these concepts, and the challenge helped them deepen their understanding. By implementing the concepts and ensuring the required performance in controlling the angular velocity of an induction motor, they gained practical experience. In this instance, the practice for the IP Ethernet communication protocol was altered to incorporate the design and implementation of PID controllers within a PLC, and practice 6 was removed to allocate sufficient time for the project's conclusion.

In conclusion, not all challenges are the same. The professor must adapt the course to support students in meeting the challenge deadlines. In our situation, specifying project milestones and tracking progress were essential to ensure the challenge was completed on time. Moreover, adjusting deadlines according to the project's advancement was crucial. Consequently, we had to exclude practical exercises from the course that did not align with the core themes of the challenges. Although certain practical exercises may not be covered, the knowledge acquired through tackling industry-oriented challenges can compensate for this. Such experience has the potential to enhance competitiveness in the job market. Another important point in the challenge is having the necessary equipment to face it. Without the proper gear, it would not be possible to overcome it.

On the other hand, the University conducts an opinion survey among students to evaluate the course and the performance of the professors. This survey serves as a feedback tool that guides our teaching practices and helps us implement improvements in the course and teaching methods. Table 1 presents the results of this evaluation, which were obtained from the University's assessment system.

The first column, corresponding to the period from February to June 2022, represents the course in the traditional format, which was divided into two parts: the theoretical section and the laboratory, with a dedication of 90 h per semester. The second and third columns correspond to the same course but incorporating the CBL model, with a dedication of 120 h per semester. The difference in hours is due to the completion of the challenge. In the traditional methodology, a project assigned by the professor was carried out, contributing to research or the development of new laboratory practices.

The February–June 2022 semester was the last time the traditional methodology was taught and the CBL approach was simultaneously introduced. Despite the assessments being similar, I believe the challenge-based approach offers extra opportunities for learning. For instance, when students develop a project with industrial support, they could become more competitive in the job market.

TABLE 1 **Teacher evaluation.**

Question	February–June 2022		February–June 2022		February–June 2023	
	Theory	Laboratory	Group 1	Group 2	Group 1	Group 2
Q1	9.77	9.86	9.89	9.85	10.0	9.40
Q2	9.69	9.86	9.89	9.92	10.0	9.40
Q3	9.54	9.86	10.0	10.0	10.0	9.20
Q4	9.75	9.86	9.83	9.77	10.0	9.40
Q5	9.62	9.86	9.78	9.69	10.0	8.60
Average	9.67	9.86	9.87	9.84	10.0	9.2

Source: University survey system. The Likert scale ranged from 1 (worst) to 10 (best). Q1. The teacher shows mastery and experience in the subject matter. Q2. The teacher challenged me to do my best (develop new skills, new concepts, and ideas, thinking differently, etc.). Q3. The teacher promoted an environment of trust and respect. Q4. The accompaniment I received from my teacher was adequate (answers to doubts, advice, feedback, etc.) Q5. Overall, my learning experience with the teacher was.

The student participation was very low. In group 2 semester Feb - Jun 2023, participation was 50%, while in the other groups it was approximately 25%. Interestingly, the group with the highest participation percentage received the lowest grades in all areas. A possible justification could be the schedule, as the first group meets from 4:00 p.m. to 7:00 p.m., and the second session runs from 7:00 p.m. to 10:00 p.m. Here are two comments from students belonging to that specific group (The commentaries are written in Spanish and the translation is literal).

Student 1:

> "He is a teacher who has a lot of experience in programming PLCs, his teaching method is very good since you will NEVER forget everything you see in the classes, whether it is what you learn in theory or what you learn during practice, such as the origin of some errors in programming, settings, etc. and how to fix or remove them."

Student 2:

> "I loved the dynamics he must give the classes although I feel that the course is poorly planned in terms of syllabus and established hours (that has to do with the planning of TEC21 for this course, not with the teacher)."

Note: TEC21 is the name given by the University to the incorporation of the CBL learning technique in the courses.

Finally, we present an excerpt from the remarks of an engineer who contributed to the development of the challenge (The commentaries are written in Spanish and the translation is literal).

> "When I was invited to participate in a challenge with students, I immediately agreed. I was excited to collaborate on a project where I could share knowledge acquired through years of work experience and, in some small way, give back to society. The environment that allowed me to pursue a university education is something I am clear about. Collaboration between educational institutions and companies enables them to work together to develop training programs that address skill gaps, foster innovation, and prepare professionals to face future challenges.
>
> Collaborating with educational institutions can transform and enrich the learning experience, opening new horizons and creating strong networks among various stakeholders. Additionally, joint efforts enhance the creation of professional networks, generating growth opportunities for both individuals and the organizations involved.
>
> I was pleasantly surprised by the adaptability of the students in finding solutions, which were approached in different ways but aimed at achieving the same result. I believe the experience would have been even more enriching if we had more frequent progress reviews and provided supporting materials in advance."

Our results show that the implementation of the CBL model has had a positive impact on the evaluation of professors and students' perceptions of the course. This is consistent with previous studies, such as Membrillo-Hernández et al. (2023), which found that the CBL approach enhances student motivation and engagement compared to traditional methods. Additionally, suggest that the transition to challenge-based teaching methods can initially cause a decrease in student satisfaction due to the learning curve associated with new methodologies. However, our data indicate that, despite a slight decrease in grades in some groups, the overall student perception of the course and the professor remains positive, suggesting a successful adaptation to the new approach.

5 Limitations and future work

The work developed in this article focuses exclusively on the teacher's experience when facing the redesigned course that utilizes CBL methodology. The experience gained in the development of industrial projects was crucial to adapting to this new work proposal. The main limitation is that it is based on personal experience and individual conclusions. There has been no opportunity to share and discuss these experiences with other colleagues to draw general conclusions. This could be addressed in future work.

Moreover, the survey applied to students focuses exclusively on the teacher's activity. However, it would be beneficial to include a series of questions oriented toward the industrial partner and the challenge.

On the other hand, based on the lessons learned, several aspects emerge that can enhance the methodology.

To enhance the partner search mechanism, consideration should be given to establishing connections with associations that represent the industrial sectors of the region. These partnerships often present real-world challenges that can be incorporated into educational programs. Additionally, create an academic department dedicated to facilitating these partnerships and develop a database that tracks the challenges undertaken and the companies involved. Such a database would allow educators to identify open problems that could be integrated into other courses. For example, in the GENERAC challenge, the company aims to replace the Arduino microcontroller with a specialized one used in its products. This specific challenge could be particularly relevant for teachers in the field of computer science.

However, our results show that the implementation of the CBL methodology in the Industrial Automation course has had a positive impact on the development of students' competencies. These findings are consistent with the studies by Ahmed et al. (2022) and Broadbent and McCann (2016), who also reported significant improvements in university-industry collaboration and in preparing students for the job market. Additionally, our results align with those of Membrillo-Hernández et al. (2019), who observed that students face initial challenges but develop critical skills such as independence and personal responsibility.

The solutions to the challenges should be reimagined to create fresh educational material that students can incorporate into their coursework. The prototypes, which have already been developed based on the challengers delivered, exemplify practical industrial applications. Moreover, it's essential for the teacher to familiarize themselves with the equipment and software employed by the company for the challenge. Prior training in the use of this equipment is necessary.

6 Conclusion

The acquisition and development of knowledge and skills by students through the CBL teaching methodology are truly invaluable and multifaceted. Students encounter authentic industrial challenges and acquire the skills to formulate well-structured solution proposals. This is where the teacher's expertise comes into play.

Balancing practical experience for students with the expertise of teachers is fundamental in CBL. While involving students in real-world projects enhances their understanding and application of theoretical concepts, it is equally essential to recognize the valuable insights gained by educators during this process. The relationship between student learning and teacher expertise contributes to a holistic and effective learning strategy.

Although our results indicate that the CBL methodology is effective, it is important to compare it with other traditional pedagogical methods. Unlike project-based learning (PBL) and problem-based learning (PjBL), CBL not only involves solving real-world problems but also fosters closer collaboration with industry, providing students with a more practical and relevant experience for their future professional careers.

Finally, participating in these types of activities pushes educators beyond their comfort zones, as each project presents unique challenges. The experience gained by participating in these industry activities is shared in this work. It provides a concise summary of tips and suggestions to help educators begin implementing this learning technique.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

VV-L: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MM-R: Writing – review & editing. RM-C: Writing – review & editing.

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Conflict of interest

MM-R and RM-C are employed by 'Rockwell Automation, Power Solutions Dept, Mexico City' and 'GENERAC Mexico Technology Center, Mexico City', respectively, at the time of publication.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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