

Multidisciplinary Capstone Project: A successful experience for engineering undergraduates

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ABSTRACT

This paper reports a single-case study of an innovative multidisciplinary capstone project (CP) designed and implemented at Universidad Católica del Norte (UCN), Chile, involving students and professors from two Engineering Schools. Grounded in constructive alignment and the CDIO (Conceive–Design–Implement–Operate) framework, the CP engaged four students from three engineering programmes in the design, creation, and validation of an automated control system and hydraulic pump test bench prototype commonly used in the copper mining industry. The project included four students from Computing and Informatics Engineering, Chemical Process Engineering, and Risk Prevention and Environmental Engineering, four faculty mentors, and a company evaluator. The study addresses three research questions concerning CP design across faculties, competency development, and replication conditions. The paper describes the objectives for meeting the company's needs and those required for graduation, the methodology to validate students' abilities and skills across disciplines, and the validation of the product delivered to the company. A three-dimensional assessment architecture (mentor evaluation, employer evaluation, and a revised rubric including discipline-specific technical indicators) is reported. The work methodology, developed under pandemic constraints, yielded a standards-aligned prototype, registered intellectual property, and positive employer evaluations. Limitations, including small sample size and single-company scope, and the institutional conditions necessary for replication are discussed.

KEYWORDS

Capstone project,
Active learning,
Industry 4.0;
Higher education.

PUBLICATION

Submitted:
29th August 2025

Accepted after revision:
1st April 2026

Introduction

In the last few decades, tertiary education teaching schemes have undergone deep changes (Flores 2020; Flores & Gómez, 2017). These changes arrived in Latin America and had an impact on teaching

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engineering majors and, more recently, on how graduation processes are generated, as is the case of the Capstone Project (CP) (Cheng et al., 2020; Bhuyan, 2021).

21st century students engaged in technological and engineering-related majors need to develop skills to face entrepreneurial challenges where technologies such as Industry 4.0 or the Internet of Things (IoT) are increasingly present. Therefore, universities offering technological or engineering-related majors must understand these new challenges and find a way to respond adequately to the current pandemic context.

The University (UCN), located in northern Chile, is aware of the above mentioned. UCN holds two schools of engineering: School of Engineering and Geological Sciences (SEGS) and School of Engineering Sciences and Construction (SESC), CP being the main tool for students' graduation from technological and engineering-related majors. This project is intended for students to apply the skills developed in the different majors to solve real problems in a company from a socio-constructivist perspective. This teaching paradigm agrees with UCN Institutional Educational Project (UCN-PEI, 2016).

Graduation via CP has been implemented in universities such as UCN to provide engineers-to-be with skills to meet the requirements of a project in a company or institution, in a real working context, where teamwork and coordination with other professionals are important factors for meeting a company's needs, and prepare the graduate for a real-world, as stated in previous studies (Lunt et al., 2008; Bringula, 2016; Meah et al., 2020). The CP graduation methodology has been previously used at UCN; however, the one here is distinctive because (1) it is a multidisciplinary project and (2) students involved followed the new curriculums developed for the different engineering areas.

Previous works as presented in (Lunt et al., 2008 and Zhang et al., 2020) suggest that one of the principles of curriculum design for undergraduate degree programs in fields as Information Technology is that 'the curriculum must provide students with a capstone experience that gives them a chance to apply their skills and knowledge to solve a challenging problem' as is indicated in (Lunt et al., 2008). In this context, a multidisciplinary CP close to industry and oriented to solving Chemicals and Computing challenges is proposed.

This multidisciplinary CP here is implemented as a UCN pioneering experience jointly with 'The company' company. It was particularly designed for students of Chemical Process Engineering (CPE), Computing and Informatics Engineering (CIE), and Risk Prevention and Environmental Engineering (RPEE). CPE and CIE are offered by SEGS, while RPEE is offered by SECS.

The paper deals with CP work context, development or implementation achieved and results both technical and academic by one CIE student, one CPE student, and two RPEE students. In addition, it reports the company's perception of results and, from the teaching dimension, the conclusions and possible future lines of work.

The design of this CP is grounded in two complementary theoretical frameworks. First, constructive alignment (Biggs, 1996) informed the mapping of intended learning outcomes to CP activities and assessment instruments, ensuring that what students were asked to do in the project genuinely corresponded to the competencies targeted in each engineering programme. Second, the CDIO framework (Conceive–Design–Implement–Operate; Malmqvist et al., 2020) provided an organising structure for the multidisciplinary project phases: students conceived the test bench requirements, designed the control and quality systems, implemented the prototype, and operated it against ISO/ANSI certification standards. Together, these frameworks guided both the pedagogical architecture of the CP and the interpretation of outcomes reported in this study.

Against this background, the present study addresses the following research questions: (RQ1) How can a constructively aligned, CDIO-based capstone project be designed and implemented to integrate students from three distinct engineering programmes across two faculties under pandemic constraints? (RQ2) To what extent does participation in such a multidisciplinary, industry-embedded CP develop the discipline-specific and transversal competencies targeted in each programme's graduate profile? (RQ3) What institutional, pedagogical, and industry-facing conditions are necessary to replicate this model in comparable higher education settings?

This paper makes three contributions to engineering education literature. First, it provides a detailed, replicable model for structuring a cross-faculty, industry-embedded multidisciplinary CP anchored in constructive alignment and CDIO principles. Second, it documents a three-dimensional assessment architecture that combines mentor evaluation, employer evaluation, and a rubric-based final presentation, demonstrating how these can be weighted into a graduation grade. Third, it offers an account of the institutional, student, and industry-level challenges encountered in a Latin American context, together with the practical mechanisms developed to address them, thereby extending current knowledge on the transferability conditions of multidisciplinary CP models in resource-constrained settings.

Work Context

For UCN, CP, based on experiences such as (Meah et al., 2020), is a tool for improving the teaching and learning process while preparing undergraduates for their engineering practicum in a real industrial world. There are previous experiences with multidisciplinary CP as reported by (Kochumarangolil & Renumol, 2018) but for the UCN this is an unexplored area as a tool for graduation methodology. Also, CP allows putting into practice skills related to the four pillars of learning: learning to be, learning to do, learning to know, and learning to live together, which are so important for education in the XXI century (Flores, 2020; Kozma & Isaacs, 2011).

In addition, CP work context makes it possible for a student to use and integrate skills developed throughout the major to solve real problems (Abd-Elwahed & Al-Bah, 2020). This may also lead to new learning objectives and students' skills more proper of a work environment (Webster, 2019; Cheng et al., 2020). For several decades, it has been well-known in Latin America that students about to graduate, particularly in engineering, show an increasing interest in participating in Capstone-type projects (Acheson, 2003; Oden et al., 2010; Gnanapragasam et al., 2015).

Four students from three engineering majors took part in this experience: one from CPE, one from CIE, and two from RPEE (one of them minoring in risk prevention and the other in quality management). Methodologies for some of these projects as reported in (Rover et al., 2014) were followed.

Company Context

This project was jointly conducted with 'The company', established in 1994 to provide mining process solutions. The company has more than 20 years of experience in fluid management, particularly pumping equipment and water treatment and purification. Its operations are directed to different industries engaged in metallic mining, industrial minerals, petrochemistry, and power generation.

The company provides technical, economical, and comprehensive solutions, according to clients' needs in different ambits such as equipment supply and pumping equipment start-up. It has a highly qualified professional team working on fluid propulsion, engineering, maintenance, automation, and control. By developing this project, 'The company' seeks to increase the quality and competitiveness of its services by designing and implementing a hydraulic testing bench. Currently, there are two test

benches in different companies from Antofagasta, though they are not automated. This involves advantages and disadvantages of the pump-testing process.

Academic Context

UCN-SEGS offers majors in Chemical Process Engineering (CPE) and Computing and Informatics Engineering (CIE), while UCN-SECS offers a major in Risk Prevention and Environmental Engineering (RPEE). Below is a brief description of their graduate profiles.

- Computing and Informatics Engineering (CIE)

CIE is a 4-year technological major offered by the SEGS Department of Computing and Systems Engineering (DCSE). DCSE-CIE main objective is to develop students' skills necessary for creating, developing, and applying knowledge and techniques in the areas of computing and informatics sciences and information, communication, and automation technologies (ICAT) to contribute to society's well-being and the country's development in the context of a knowledge-based economy.

CIE has been offered since 1994. Following the authors as (Nikolitsa-Winter, 2014), its graduate profile defines a comprehensive and productive professional, with ethical principles and a broad sense of social responsibility and commitment to development on a regional and national basis. This graduate profile was restated in 2016 to adapt it to current demands. CIE provides knowledge on basic sciences such as math and physics, engineering sciences such as systems theory, programming, informatics engineering, and computing technology, computing science, software engineering, databases, and communication networks.

This profile is complemented with knowledge about human and social sciences (administration sciences, oral and written language, and technical English). It also includes the development of abilities and skills such as self-learning, teamwork, problem-solving, effective communication in oral and written Spanish, critical thinking, the ability to communicate in basic oral and written technical English, and the ability to solve engineering problems from a systems perspective on an operational basis.

Concerning specific skills, the profile considers developing skills to adapt current technologies to organizational changes; the ability to analyze, model, and develop systems, processes, and products based on technologies; and the ability to understand and take problems from the real world to solve them from a computing perspective.

- Chemical Process Engineering (CPE)

CPE emerges as a proposal to modernize the Chemical Process Executive Engineering (CPEE) major, based on CDIO model: conceive, design, implement and operate (Malmqvist et al., 2020). This model comes from the need to balance engineering knowledge and practice. It intends to develop a comprehensive curriculum and implement learning experiences. It is based on a syllabus, determining the scientific and disciplinary knowledge students must obtain while developing personal and interpersonal skills. The model also determines engineering practice skills related to the construction of value-added products associated with engineering systems conception, design, implementation, and operation, conceptualized for each disciplinary area, making it a technology-based major focusing on process plant systems operation and implementation.

At present, CPEE has a registration of 100 students, most of whom changed from civil engineering majors, thus having a second academic chance and eventually a good economic status, given the great

labor opportunities for these professionals. This is aligned with UCN mission, that is, contributing to people's development, and its vision, that is, being an agent of change. On an international basis, the major lies within CDIO areas for CHEMICAL ENGINEERING, in a similar way (Malmqvist et al., 2020).

A UCN-CPE graduate is a comprehensive and productive professional, with ethical principles and a deep sense of social responsibility, committed to permanent development on a regional and national basis. His training involves the acquisition and use of knowledge and tools allowing him to update constantly and show initiative to adapt to the demands of the environment. A UCN-CPE graduate shows generic competencies ineffective communication, permeability to change, decision making, and time and resource management. In addition, he can work effectively with technical equipment and aims at improving productive processes continuously.

As an engineer, he is able to administrate chemical process projects and contracts, considering clients' needs, costs, and risks for their correct implementation. He is also competent in proposing, operating, implementing, and supervising industrial processes, considering their impact on a comprehensive social, legal, economic, and environmental context.

- Risk Prevention and Environmental Engineering (RPEE)

RPEE aims at studying, learning, and applying risk control norms, making industrial work safe by itself and for the environment. Concerning graduate profile, a UCN-RPEE graduate is a comprehensive and productive professional, with ethical principles and a deep sense of social responsibility, committed to permanent development on a regional and national basis. His training involves the acquisition and use of knowledge and tools allowing him to update constantly and show initiative to adapt to the demands of the environment. A UCN-RPEE graduate shows generic competencies in effective communication, permeability to change, decision making, and time and resource management. In addition, he can work effectively with technical equipment and aims at improving productive processes continuously.

As an engineer, he is able to formulate and administer engineering projects on labor and environmental risk management and control, identifying clients' needs, costs, and risks for a correct implementation. He is also able to operate, implement, and supervise engineering management and control processes concerning labor and environmental risks, considering their impact on a global social, legal, economic, and environmental context.

Implementation and formative objectives

CP objective is to encourage students to develop the abilities that will help them prepare for the real world, such as thinking critically, solving complex problems communicating orally and in writing, doing research, working in multidisciplinary teams, planning, and self-learning, among others, in the context of a real company, as stated by (Bringula, 2016; Cheng et al., 2020; Meah et al., 2020; Gnanapragasam et al., 2015).

In this context, the general objective is to apply CP methodology to develop students' skills, considering factors such as:

1. Focusing work on the solution of a complex problem described in real parameters, that is, a problem involving several aspects since it deals with different technologies applied in the mining industry.
2. Doing collaborative group work, not only among students but also with the company's personnel, keeping in mind personnel and company goal achievement.

3. Managing CP work team, consisting of students from the three majors, mentors (one per each major and one sharing mentoring and coordination), all of them closely coordinated with a representative from the private company receiving the solution.
4. Proposing a problem by academics who are directly in touch with the company and defining its design and execution jointly with the sponsoring company.

As said before, for this CP two industry subareas were considered; the first is related to the testing of pumps and the second is related to the integration and operation of the pump in a safe industrial environment. In this context and in order to achieve the general objective mentioned before, 8 specific objectives were defined. These objectives are described below, 1-4 corresponding to the first subarea and 5-8 to the second subarea.

1. Determining operational variables for hydraulic test certification.
2. Defining instrumentation for implementing certified hydraulic tests.
3. Designing the hydraulic test bench control philosophy.
4. Implementing an automated hydraulic test bench control system.
5. Describing the operational hydraulic test certification service model.
6. Determining the treatment of the operational hydraulic pump test bench risks.
7. Designing the conceptual quality management model for the hydraulic pump test certification service.
8. Preparing documents for a standardized hydraulic pump test bench service implementation.

Syllabus Design Methodology

To attain the objectives, from a teaching viewpoint (CP is considered as a thesis-type activity) and according to the company's interests (having an automated control prototype for the hydraulic test bench of centrifugal pumps), a 4-stage methodology was designed, as described below.

1. CP work environment and problem detection. Reviewing the theoretical background of the equipment (e.g., types of hydraulic and centrifugal pumps. Etc.) and the economic-productive activity of the company, among others. Reviewing methodological aspects of the engineering disciplines involved such as methodologies to design and develop automated control processes and software engineering to detect the problem and set the project objectives.
This stage involves investigating for determining the problem appropriately, planning the project, and defining the time and resources needed to attain its goal.
2. CP design and implementation. Following the methodological stages of the disciplines involved to create a prototype and testing its operation on-site and at the lab, meeting the company's quality standards and RPEE quality control standards.
3. CP control and management. Checking the accomplishment of stage 2 and validating academic progress (documentation supervised by mentors) and advances in the solution of the company's problem.
4. Product start-up and presentation of results. Testing and validating the prototype at the lab and delivering it to the company. Presenting academic results:
 - (i) weekly meetings with each mentor, either group (including the four students) or individual (according to the different disciplines, e.g., CIE student and DCSE academic) meetings,

- (ii) presentations of partial results every two weeks, and
- (iii) pre-final (a month before ending CP) and final presentation of results.

Due to the pandemic, the final presentation was done via computer tools. The assessment rubrics compared the attainment of objectives described in section 2.3 and those attained throughout CP development.

The experience in designing and executing this multidisciplinary CP shows several previous results: three previous CPs in CPE, two in CIE, and two in RPEE. This project aims to develop and implement an automated control system and manage quality and risks for ‘The company’ hydraulic centrifuge test bench. To attain this goal, several specific objectives separated into two subareas were devised: an automated control area and a risk and quality control management area.

Table 1. Academic requirements by major. It is important to highlight that all majors have VIII semesters.

Engineering major	Specific academical requirements		Engineering skill requirements
Computing and Informatics Engineering (CIE)	The student has shown all subjects taken (from I to VII semester) and their corresponding marks, particularly related to software engineering, object-oriented programming, and software projects	Professional internship passed and their corresponding marks	Skills for working with software design methodologies and programming highly qualified software applications in a teamwork environment Research and autonomous work skills in the field of computing and informatics Oral and written communication skills for presenting results either on a document or via computing reports
Chemical Process Engineering (CPE)	The student has shown all subjects taken (from I to VIII semester) and their corresponding marks	Professional internship passed and their corresponding marks	Skills for elaborating technical reports (1-5 pages in Spanish or English), resulting from equipment or unit operations Skills for designing diagrams using terms related to general chemical engineering processes Skills for elaborating technical reports containing industrial process diagrams, using technical language Skills for interpreting transmission components and mechanisms and signal conversion
Risk Prevention and Environmental Engineering (RPEE)	The student has shown all subjects taken (from I to VIII semester) and their corresponding marks	Professional internship passed and their corresponding marks	Skills for interpreting manuals and norms in the field of risk prevention. Skills for interpreting norms and instruction manuals to generate instruction, operation and safety manuals, based on national and international standards

Regarding the skills necessary in each major to make students' work and contributions compatible, the methodological steps are complemented by section 2.2, creating a task sequence related to students' abilities for solving the problem posed. Table 1 summarizes the academic requirements of each major in terms of abilities.

Challenges

When working on a project that integrates multiple branches of engineering, the ability to clearly understand and effectively communicate ideas becomes essential. Equally important is the capacity to actively listen and incorporate the perspectives of others. These competencies are fundamental to the success of any collaborative effort. In the context of multidisciplinary Capstone Projects (CPs) involving students from different engineering programs, these experiences compel participants to develop not only technical skills but also the ability to lead and, conversely, to be guided as members of a cohesive team.

Although the primary goal of a Capstone Project is to enhance students' skills and competencies, such development would not be possible without the coordinated efforts of faculty advisors and the active engagement of industry partners providing real-world projects. Creating a meaningful dialogue between professors from different disciplines is not a straightforward task; however, it is a necessary step that requires strong institutional commitment and support.

- Institutional Challenges

The first major challenge faced in the implementation of this CP stemmed from the formal procedures of Universidad Católica del Norte (UCN). The project required integrating students from three distinct engineering programs, distributed across two separate faculties, while also ensuring close collaboration with the partnering company. Achieving this level of coordination demanded the development of a structured communication methodology focused on three core principles: clarity, active listening, and empathy. This framework ensured that messages were accurately conveyed and that information flowed seamlessly in a bidirectional manner among all stakeholders.

The faculty advisors played a pivotal role in enabling this process. At the inception of the project, they convened to establish the specific academic objectives of each engineering program and to define the expected learning outcomes for students approaching graduation. This early alignment allowed for the design of evaluation criteria that accurately reflected the interdisciplinary nature of the project while maintaining the academic rigor required by each program. The result of this collaborative effort was the creation of a unified assessment rubric (Table 3), which provided a transparent and fair mechanism for evaluating both the technical achievements and the professional growth of the students.

- Student Challenges

Once the evaluation framework had been established, attention turned to the challenge of successfully collaborating within a multidisciplinary team. The project comprised four students, each representing a different engineering specialization. To succeed, they need to not only communicate effectively but also recognize and respect the leadership roles that each member held within their respective discipline.

To facilitate this process, an initial effort was made to standardize the team's baseline knowledge. This was achieved through the implementation of a series of "knowledge capsules," which were short, focused sessions designed to introduce key concepts, processes, and methodologies from each discipline in a simplified and accessible manner. These sessions were delivered by faculty advisors, who distilled complex technical content into practical knowledge that could be understood by students outside their field. The underlying premise was that genuine collaboration requires not only willingness but also a foundational understanding of the knowledge that informs each discipline's approach.

Given the relatively short duration of CPs, typically ranging between six and twelve months, this knowledge capsules required careful planning and structuring. Students had to quickly absorb and apply new concepts while simultaneously advancing their project work. Similarly, faculty advisors needed to demonstrate exceptional pedagogical flexibility, adapting their expertise into a format that could be effectively communicated across disciplines without compromising the integrity of their field. This strategy proved instrumental in establishing a common ground for interdisciplinary dialogue and ensuring that all team members could contribute meaningfully to the project's success.

- **Industry Challenges**

In the Chilean industrial landscape, there is a growing demand for innovative ideas and practical solutions. However, this demand is often constrained by a perpetual cycle of immediate operational pressures, leaving little room for long-term strategic planning. This dynamic has created a persistent disconnect between industry and academia: while companies seek immediate, actionable outcomes, academic research tends to operate on longer timelines, often spanning several years, which limits its direct and timely impact on productivity and competitiveness.

Addressing this disconnect requires a significant cultural and operational shift from both stakeholders. On one hand, industry leaders must recognize that the development of effective, sustainable solutions cannot always be instantaneous. On the other hand, academic institutions must adapt to the pace of industrial operations to avoid remaining isolated from real-world demands. Capstone Projects (CPs) offer a practical and balanced approach to bridging this gap. By framing industrial challenges as short-term, well-defined projects, typically with a duration of six months, industry partners can benefit from rapid, targeted insights, while academic teams engage in applied research that remains methodologically rigorous.

In the present work, this challenge was approached through a structured collaboration between the academic team and the industrial partner. Weekly meetings were held throughout the project, fostering continuous communication among students, faculty advisors, and industry representatives. These interactions ensured that expectations remained aligned and that emerging issues could be addressed in real time. Furthermore, clear and specific objectives were jointly defined at the outset of the project, along with mutually agreed timelines for deliverables. This structured coordination enabled the academic team to produce timely, relevant outputs while maintaining the depth and analytical rigor characteristic of scholarly work, thereby generating value for both academia and industry.

Research Design and Methods

Study Design and Context

This study adopts a single-case explanatory design (Yin, 2018), which is appropriate when the aim is to investigate a contemporary phenomenon in depth within its real-life context and when the boundaries between the phenomenon and context are not clear. The case is the multidisciplinary CP conducted at Universidad Católica del Norte (UCN) during the 2020 academic year, under pandemic conditions that required a remote-first collaboration modality. The case was selected purposively as a first-of-its-kind cross-faculty CP at UCN, offering an opportunity to document and analyze the design, implementation, and assessment of a model whose preconditions, challenges, and outcomes had not previously been examined at this institution. The unit of analysis is the CP as a pedagogical system, encompassing its design architecture, student performance across three assessment dimensions, and industry partner evaluation.

Participants and Roles

Participants comprised four undergraduate students (one from CIE, one from CPE, and two from RPEE), four faculty mentors (one per discipline plus one shared coordinator), and one industry representative from the partner company. All participants were involved in the CP as part of their normal academic or professional roles; no additional recruitment was required. The faculty mentors acted simultaneously as pedagogical designers, subject-matter assessors (E-1), and rubric calibrators. The industry representative acted as project sponsor and employer evaluator (E-2). Ethics approval and informed consent procedures followed UCN institutional guidelines for educational research involving student data generated in the normal course of academic activity. [Note to authors: please confirm the applicable institutional ethics reference number and insert it here.]

Data Sources and Instruments

Three data sources were used, corresponding to the three assessment instruments described in Section 3. Instrument E-1 (direct mentor assessment) consisted of structured observation records produced during weekly and bi-weekly individual and group meetings; each mentor evaluated their corresponding student(s) against the competency indicators defined in the graduate profile for that discipline (Table 1). Instrument E-2 (company evaluation) consisted of a structured evaluation form completed by the industry representative at the end of each bi-weekly progress meeting, rating the team's alignment with project objectives and professional conduct. Instrument E-3 (final presentation rubric) consisted of the thirteen-indicator rubric described in Table 3 and scored during the final oral presentation by the full panel of mentors and the industry evaluator. In addition, technical artefacts – the physical test bench prototype, control software, P&ID diagrams, risk register, and quality instruction manuals – were used as documentary evidence to corroborate E-1 and E-3 technical indicator scores.

Reliability, Validity, and Analytic Procedures

To address construct validity, assessment indicators were mapped directly to the graduate-profile competencies of each engineering programme (Table 1) and to the relevant ISO/ANSI standards, ensuring that what was measured corresponded to the competencies the CP was designed to develop. To address internal validity, mentor assessments (E-1) were conducted independently before group progress meetings, and E-3 rubric scores for Group A technical indicators were double-marked: the disciplinary mentor and one additional evaluator scored independently, with a target inter-rater agreement of Cohen's $\kappa \geq 0.70$; discrepancies exceeding one scale level were resolved through moderation. E-2 scores were treated as a single-rater measure and interpreted accordingly. Descriptive statistics (means and ranges) were calculated for E-1, E-2, and E-3 scores across all four students.

Given the exploratory, single-case nature of the study, no inferential statistics were applied; the analytic goal was to document the pattern of outcomes across assessment dimensions rather than to test hypotheses. Transferability was addressed by providing a detailed account of the institutional context, the challenges encountered, and the minimum replication conditions identified (see Limitations and Transferability section).

Results

Automated control was implemented in the hydraulic test bench to improve the time, standardization, and optimization of the service provided by the company, comprehensively managing the quality and risks associated with the processes involved. This implementation allowed obtaining the characteristic curves of different centrifugal pumps. In this way, the performance of each tested pump could be compared in practice. Also, a user's interphase and computerized records were implemented to document the tests. A user's manual for the test bench was devised, which contained technical data, risks (ISO-31010 standard), and quality instruction manuals.

Technical Results

Prominent technical results were the following: first, a test and a test bench were designed according to ISO 9906:2010 (ISO I, 2012). The quality-related team, consisting of two RPEE students, determined that, according to these standards, behavioral tests made up the fundamental part of acceptance tests since their objective was to detect the real operational conditions of the pump, the obtention of characteristic curves being particularly important, according to standards such as ANSI/ISA-5-1 (Iverson & Verhappen, 2009). The project team defined, according to ANSI/HI 14.6-2011 standard (ANSI/HI, 2011), that the pumps show different degrees of acceptance, depending on the agreement between the maker and the buyer or the type of service the pump will provide.

The development team (students and mentors) worked on the first methodological stage and made a technological recommendation to attain the general objective of the project. In the second methodological stage, designs were generated from two perspectives: for developing the control system (computer tool) and for designing the certification innovation from the risk management and quality control viewpoint.

In this regard, data-collection devices such as interviews were developed and administered to the company's personnel. With the data obtained, related to needs, characteristics, and the test bench team, a baseline of the area was determined. Also, forms were designed to record findings and deviations detected before CP start-up. Parallely, documents related to the company's mechanic workshop procedures such as pump reception, treatment, maintenance, repair, and delivery were required to analyze the operational, administrative, and technical variables of the service offered, within the framework of the company's mission and vision.

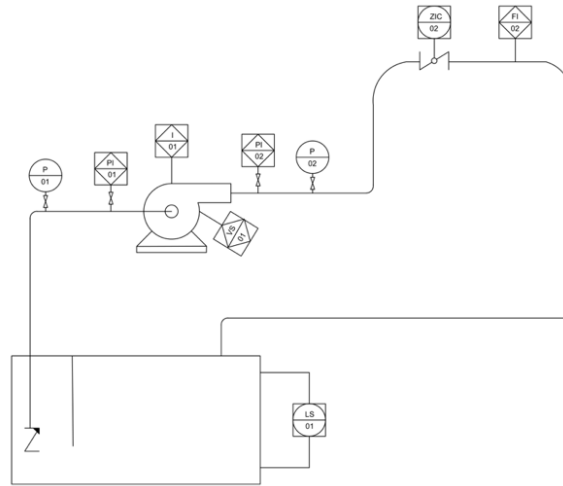


Figure 1. P&ID test bench diagram

Table 2. Main operational variables were measured at the hydraulic test bench.

Variable	Dynamic test range
Flow	5-543 [m ³ /h]
Suction pressure	±1 [Bar]
Discharge pressure	0-20 [Bar]
Power	100 [HP]
Volume	10 [m ³]

For designing the control system, an analysis of procedures and work philosophy was conducted to control the test bench. The test bench control philosophy includes the parameters associated with the corresponding tests, involving a sampling period and high and low-temperature alarms if there were a failure during the test bench operation. The control philosophy deals with a series of decisions based on concepts that make it possible to specifically attain the objectives previously set. A relevant result from this stage was the recommendation of a sensor selection to conduct the P&ID process. Figure 1 shows P&ID conducted by students, where an interrelationship between sensors and actuators using ISA 5.1 (ANSI-ISA, 2009) is observed.

In the second methodological stage, results from the computerized control system implementation were obtained. The first of these was the identification of operational variables to be controlled and measured at the hydraulic test bench. Table 2 shows the variables and ranges of the dynamic tests used for data generation. These data were stored in a database designed and implemented for this CP. This database is the second tangible result. The third one is the computer code to implement the computing solution. This code was generated using Visual Basic. The four students participated in the test bench design and implementation, along with the mentors from the three majors, who actively guided students and also indirectly in the lab prototype design, construction, validation, and testing.



Figure 2: Lab prototype test bench.



Figure 3. Inner (left) and outer (right) picture of the control panel.

The test bench was designed as a lab prototype, as shown in Figure 2. The labels show the prototype components, as described below: Label 1 shows the water tank where pump suction and return are tested; label 2 shows the check valve for measuring water flow; label 3 shows the centrifuge pump; label 4 shows the suction pressure transducer; label 5 shows the discharge pressure transducer; label 6 shows the pneumatic valve; label 7 shows a Venturi tube section used for fluid transport throughout the system; and label 8 shows the level control sensor since a change in level change may occur during centrifuge pump operation.

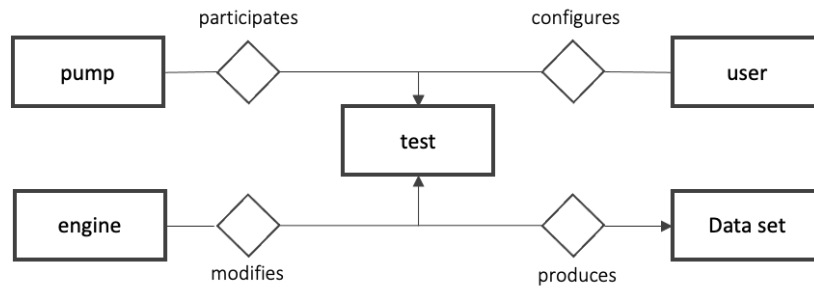


Figure 4. Simplified entity-relationship diagram. Basic entities for the test bench prototype database design.

For a proper lab prototype operation, a control panel was developed, as shown in Figure 3. The picture on the right shows the front view and the left one shows the inner part of the panel and the components selected and integrated for a proper test bench operation. Since it is not a student’s objective to have the skills for developing, calibrating, and starting up the control panel, much of its design and implementation was undertaken by Professor CL, that is, the attachment of the equipment used in the test bench to the control panel was conducted jointly by professor CL and the four students, thus, providing them with additional learning.

In addition to the physical test bench prototype implementation, a system’s database storing data generated during tests was designed. As a result of the logical database design, entities and characteristics were identified and then implemented into a relational database by using MySQL² free database management software.

Figure 4 shows a simplified diagram of the main entities identified for the process. The CIE and CPE students were in charge of developing both the software and the database, testing the software, and creating the user’s manual. Similar to the control panel, students were supported by a professor, in this case, professor VF, for task planning, database manager selection, and database implementation and design. The database allowed temporarily storing data generated during tests and using them to test and validate the technical use of the lab prototype test bench. The interface for visualizing data from the database is also a project result; however, it cannot be visualized or described here due to the company’s protection policy.

Academic results

The abovementioned corresponds to the results of the technical solution implementation. However, CP also dealt with a multidisciplinary academic dimension, that is, as a graduation activity for four undergraduates from two different Schools.

The academic assessment was planned and coordinated so that progress could be properly reported, focusing on the CP objective attainment. Progress in academic work and company results were based on the planning designed at the beginning of the project and written on a CP Gantt chart, being both well-known by professors and the company. To measure the objective attainment, three dimensions were defined, as described below:

1. Direct assessment of each student by each professor (Instrument E-1). It consisted of meetings for determining each student’s advances in the corresponding work area, and checking their agreement with both the project objectives and group work, as a whole. These assessments

² <https://mysql.com>

were first face-to-face, then once a week for six weeks, and finally, every two weeks until the 14th week. The rest of the workgroup could also participate in the meetings if students required the group opinion to analyze a task. For example, for database design, the four students were required to participate in several meetings with Professor VF from CIE major. Also, the four students had to meet several times with professor CL from the CPE major.

2. Result assessment from the company (Instrument E-2). It consisted in determining advances according to the company's needs and objectives. So, meetings with the company's representative were held every two weeks until the end of the project. Typically, the four students and the academic coordinator, professor MN, participated in these meetings, the latter every three meetings.
3. CP result assessment or final presentation (Instrument E-3). It consisted in determining the project objective attainment, both academic and technical. To measure these achievements, assessment rubrics were designed, as shown in Table 3. Nine descriptors were developed to measure different aspects corresponding to related abilities.

The revised rubric encompasses thirteen descriptors organised into two groups. Group A (indicators 1–4, 40% combined weight) addresses discipline-specific technical competence: indicator 1 evaluates standards conformance and design rationale (CIE/CPE); indicator 2 evaluates verification and validation evidence for the prototype and software (CIE/CPE); indicator 3 evaluates risk identification, assessment, and control measures applied (RPEE); and indicator 4 evaluates quality management documentation and instruction manual completeness (RPEE). These indicators were assessed by the corresponding disciplinary mentor using a structured checklist aligned with ISO 9906:2010, ANSI/HI 14.6-2011, and ISO 31010 criteria, and were scored independently by a second evaluator (inter-rater reliability target: Cohen's $\kappa \geq 0.70$). Group B (indicators 5–13, 60% combined weight) addresses transversal presentation and communication competencies. Indicators 5 and 6 relate to subject mastery and content development as evidenced in the oral presentation. Indicators 7 and 8 evaluate self-confidence and fluency. Indicators 9, 10, and 11 assess conclusion quality, presentation structure, and didactic support materials. Indicators 12 and 13 assess quality of responses to panel questions and argumentation, including both individual and group perspectives.

Each of the three assessment dimensions described above is considered in the final graduation activity average. E-1 and E-2 weigh 30% of the final average, both being required for the final presentation. E-3 weighs 40% of the final average and is obtained by using the rubrics in Table 3. As shown in Table 3, each indicator is assigned a weight expressed as a percentage, which is later expressed as a grade for E-3.

The Chilean grading scale ranges from 1.0 to 7.0, with the minimal passing grade being 4.0. Once a grade for the three assessments (E-1, E-2, and E-3) is obtained, the partial grades are multiplied by each percent, the final grade being the weighted sum of the grades. The four CP students' final grades were calculated as described above.

Another quite remarkable result of this innovation is its registration at the Chilean Service of Cultural Patrimony as an intellectual property managed by UCN, including both mentors and undergraduates participating in the CP project. In this way, not only the academic and company objectives were attained, but also copyright was registered, thus significantly contributing to the technological development objectives posed in UCN institutional development plan. The innovation is registered as *Software de Control de Banco de Pruebas de Bombas Industriales* (Industrial Pump test Bench Control Software), number 2020-A-8980 (UCN-2020-A-8980, 2020)

Table 3: Revised assessment rubric (E-3): Group A – Discipline-specific technical competence (indicators 1–4, 40%); Group B – Presentation and communication competencies (indicators 5–13, 60%). Group A indicators were double-marked by the disciplinary mentor and one additional evaluator; Group B indicators were scored by the full panel.

Nr.	Rubric	Exceeds expectations (6.0 a 7.0)	Meets expectations (5.0 a 5.9)	Approaches expectations (4.0 a 4.9)	Does not meet expectations (< a 4.0)	Percent (%)
1	Subject mastery	Shows mastery of the topic; explains without reading slides	Masters the topic, but sometimes reads during the presentation	Shows conceptual problems; does not master the topic; sometimes reads during the presentation	Reads during most of the presentation	15%
2	Content development	Develops contents properly, according to the topic complexity and depth	Makes a good presentation of the topic, but does not deal with some important issues in depth	Does not develop the topic appropriately, nor the most important contents	Presents poor and poorly developed content	10%
3	Self-confidence	Shows self-confidence for communicating knowledge; highlights the most accurate and pertinent data	Doubts when communicating knowledge; does not highlight the most accurate and pertinent data	Doubts throughout the presentation; does not present relevant data; presents some non-pertinent data	Doubts throughout the presentation; presents the topic unclearly; presents irrelevant and non-pertinent data	10%
4	Fluency and coherence	Shows fluency, coherence, and clarity	Makes at least two mistakes affecting fluency	Is not fluent; makes more than three mistakes affecting coherence and clarity	Is neither clear nor coherent	10%
5	Conclusion	Makes an appropriate final synthesis	Makes a final synthesis, but makes mistakes	Makes a poor synthesis; does not make a final synthesis	Makes an unclear closing; does not make a final synthesis.	10%
6	Structure and order	Does a clearly organized presentation visually acceptable; respects schedule; captures attention from beginning to end	Does a clearly organized presentation visually acceptable; does not finish on time; does not contextualize some ideas	Does a poorly organized presentation visually accepted; does not finish on time; does not contextualize some ideas	Does a disorganized presentation visually unacceptable	10%
7	Didactic support	Uses didactic resources, showing good work and creativity	Uses 1 or 2 didactic resources	Uses 1 didactic resource	Does not use didactic resources or the chosen ones are not appropriate	10%
8	Answers	Answers questions accurately; use clear arguments	Answers questions, but doubts and uses a few arguments	Does not answer one of the questions; doubts about the others; uses a few arguments	Does not answer questions accurately	15%
9	Argumentation both personal and in a group	Uses arguments to support his/her ideas; puts emphasis on main ideas	Uses arguments to support his/her ideas: does not clearly follow the main idea	Uses poor arguments; does not clearly follow the main idea	Expresses ideas little or no related to the topic.	10%

Limitations and Transferability

Several limitations of this study must be acknowledged. First, the small sample size (four students, one company, one project cycle) restricts statistical generalisation and means that observed outcomes cannot be attributed solely to the CP design. Second, single-company collaboration introduces a potential halo effect: the industry evaluator was personally invested in the project's success, which may have inflated E-2 scores. Third, intellectual property constraints prevented the public release of key software artefacts and the full database interface, limiting independent verification of technical quality outcomes. Fourth, because the project was conducted entirely under pandemic conditions, the remote-first work modality may have affected both collaboration dynamics and mentor oversight in ways that are not representative of a standard implementation. Fifth, the absence of a comparison group (e.g., a concurrent single-discipline CP cohort) means that claims regarding the superior developmental value of the multidisciplinary format remain suggestive rather than confirmatory.

Regarding transferability, the present model is most likely replicable in institutions that satisfy the following minimum conditions: (1) formal governance mechanisms that allow cross-faculty enrolment and grade consolidation, since without institutional authorization for shared academic credit this CP structure cannot operate; (2) a stable industry partner willing to commit a named representative to weekly project meetings for the full CP cycle (six to twelve months), as the cadence of industry feedback was essential to aligning technical outputs with real operational requirements; (3) at least three disciplinary mentors who can coordinate assessment criteria before the project begins and who accept shared responsibility for rubric calibration; (4) laboratory or workshop access sufficient to build and test a physical prototype, which in this case required controlled access to hydraulic test infrastructure; and (5) institutional support for intellectual property registration procedures, given that the IP outcome was both a motivational factor for students and a formal deliverable for the industry partner. Programs that cannot guarantee these conditions should treat the present model as a design-reference rather than a turnkey replication. Detailed program profiles included in this paper could be relocated to an appendix in a future version to allow fuller elaboration of these transferability conditions in the main text.

Conclusions and future lines

This paper describes a multidisciplinary Capstone Project (CP) as a pioneer experience for undergraduate students from Engineering majors from the UCN, where undergraduate students from Computing and Informatics Engineering, (CIE), Chemical Process Engineering (CPE), and Risk Prevention and Environmental Engineering (RPEE) majors worked together to design, construct, and test a lab prototype test bench for hydraulic pumps commonly used in the copper mining industry.

The paper also describes the CP design to include students from different engineering majors and describes the skills required and used by students to plan and conduct the stages of the project. In addition, it describes the assessment of three dimensions: technical skills, skills from the company's perspective, and skills for presenting results and communicating effectively, the latter including the assessment of students' critical skills concerning their work and results.

The CP was characterized by an innovative methodology, particularly designed for students from the three engineering majors to work in a group. Two of these majors, CIE and CPE are offered by the School of Engineering and Geological Sciences (FECS), while RPEE is offered by the School of Engineering Sciences and Construction (SESC). This experience shows that it is possible to integrate the resources and curriculums from two UCN engineering schools into a CP.

Like the work methodology, assessing three dimensions was an innovation that allowed a constant follow-up. Also, how students' final average was calculated was novel. Hence, a comprehensive assessment was conducted, involving the use of both previously-learned technical skills (Table 1) and resources and tools for effectively communicating work done, synthesizing, and working in a group.

The work methodology was positively evaluated by both students and the industry partner, as reflected in employer evaluation (E-2) scores and feedback collected during bi-weekly progress meetings. [Note to authors: insert summary E-1, E-2, and E-3 grade statistics here to substantiate this claim with empirical evidence, as requested by reviewers.] It made continuous permanent communication easier in four ways: first, among team members; second, among students and mentors, third, between students and the company; and finally, among students, mentors and the company's personnel since both mentors and the company representative used the assessment rubrics in Table 3. The work methodology, assessment, and the description of skills and metrics to measure results make up a 'model' to be replicated in future experiences and Capstone-type projects, either multidisciplinary or with students from only one major.

Future lines

As a future line of work, a Capstone Project subject could be designed and taught in the last terms. This subject could be a great contribution for students so that they could learn the characteristics of this type of graduation tool, while, at the same time, they could clearly learn about the skills to be developed in the context of real-life projects within an Engineering 4.0 environment in the XXI century.

Funding: The project did not receive any external funding; however, students received payment from the company for their work.

Conflicts of Interest: The authors declare no conflict of interest.

Availability of data and material. Data and materials have been generated in collaboration with 'The company', and now they are for commercial use. Therefore, they are not freely available.

Code availability. Code has been generated in collaboration with 'The company', and now they are for commercial use. Therefore, they are not freely available.

Authors' contribution: DP, VF and CL worked together to define both the required academic skills and the technical characteristics for the multidisciplinary Capstone Project. DP, VF and CL were working on the technical solution of the test database, test model and test bench. DP was heading the work with the client (The company). CL and VF worked on the methodology, the documentation and creation regulations and testing, according to the industry standards, security policies and regulations. Coordination was in charge of CL.

Acknowledgments: The authors wish to thank the four students (AB, NF, JH, GL) from the three University engineering majors for their active participation in and great contribution to the project. They were committed to planning, reporting on time, and academic assessment, their contribution being rewarding for academics. The authors also wish to thank 'The company' for its collaboration and active participation, particularly engineer DP, who worked together with students. Particularly, he

provided information on the company's processes, work methods, standards and norms, and other particularities so that students could get a close view of an engineer's job in a real context.

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