# Engineering Final Project

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Capstone projects represent an opportunity for students to work in real challenges proposed by industry partners. Companies also have an opportunity to better understand their challenge with the students' support. This document describes the design and implementation of a senior capstone project in an engineering undergraduate program in Brazil, where capstones are not standard practice neither for students nor industry. Several challenges were encountered, such as interacting with industry, designing how the course should be conducted, and how to evaluate students. The capstone program implemented is in its early iterations, but already shows that students can effectively interact with and deliver prototypes to industry. Feedback from students and industry shows that, beside good technical results, the capstone project improves other social skills in the students.

Keywords: Capstone Design Course, Engineering Education, International Capstone, Industrial Projects

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## Introduction

Capstone projects are becoming common around the world and identified as indispensable for student formation and school reputation[1]. Nevertheless, implementing a capstone project within a cultural setting unaccustomed with this kind of learning strategy brings several challenges, ranging from having students without a clear understanding of capstone project goals to companies not prepared to embrace and support capstone projects.

This document presents our experience in designing and implementing a capstone project in engineering at [[Blind]] College in Brazil, which started three engineering programs in 2015: Computer, Mechanical, and Mechatronics Engineering. These entire new programs have a mission of applying modern pedagogical strategies to improve learning, with a design focused on industry needs while providing a more hands-on learning experience[2].

The proximity between industry and university is not very common in Brazil, but there is a growing interest for improving this proximity nation-wide[3]. Capstone projects are starting to be applied in the national context. A recent initiative at University of São Paulo put together students from different schools in a capstone project, exploring design strategies for conducting projects[4]. An international approach was conducted for a Capstone Project between Federal University of Parana and Florida State University in USA on the development of a tri-generation system for distributed power[5].

The remaining of the document presents design strategies for the capstone project, how it was implemented, and results of the first iterations.

## Capstone Project Overview

[[Blind]] ´s engineering capstone project, unsurprisingly named "Final Engineering Project" in our institution, intends to bring students and industry closer in order to develop engineering solutions that meet real and truly relevant demands compatible with student's formation. Students acquire professional experience, putting their knowledge and skills into practice in a real setting while being guided by mentors at the company and by college faculty.

The capstone project is mandatory for all engineering students and is an intensive immersion activity with a duration of one academic semester. The workload demanded by the capstone project is equivalent to four regular courses (around 300 hours). Students may only take one or two electives in the semester alongside the capstone project and are forbidden to take any internship during the period.

Students have an academic advisor who is a faculty member with the specific technical and professional knowledge to support them according to the project needs. This advisor has weekly meetings with their students. Each advisor can assist at maximum two teams per semester.

On the other side, organizations are invited to propose projects, and are allowed to participate in the process based on their reputation for engineering solutions and their willingness to follow the entire project development process. Organizations are not required to compensate financially, but must have a commitment to mentor students, meeting them with regularity for project discussion and development.

### Learning goals

A capstone project allows students to experience a real project scenario but in a supervised manner, where mentors and advisors guide students and point out opportunities for learning and knowledge, skills, and abilities improvement. This approach stands in slight contrast with internships and trainee programs, where supervision and tolerance to failure is usually less pronounced – both a capstone project and apprenticeship initiatives in industry are learning activities as well as recruiting and selection tools, but capstones tend to focus on the former while apprenticeships may place more emphasis on the latter, in our experience.

Hence, the proposed capstone project has five learning goals, which are constantly tracked during the semester:

- **Technical Execution**: design, prototype, develop, validate, test and document a real engineering solution;
- **Organization**: choose, follow, adapt and judge a working methodology appropriate to the project;
- **Communication**: communicate effectively and assertively with stakeholders, keeping information and expectations up to date with project objectives and progress;
- **Teamwork**: identify and enable the roles and responsibilities of all team members, ensuring the engagement of project colleagues;
- **Design/Entrepreneurship**: identify stakeholder needs and expectations, addressing potential risks and necessary negotiations, analyzing their technical and economic feasibility.

Assessment instruments include: a set of technical reports (preliminary analysis, mid-project progress report, and final report), evaluation of the developed solution by an advisory committee, mid and final presentations (which takes 30 minutes each), peer-evaluation (from teammates), self-assessment, and feedback from the partner company. Not all assessments are used for grading students directly, but rather assist the advisor in constructing the final grades per learning goal.

Each of the learning goals have a set of evaluation rubrics for the team and another for the individual. These rubrics take input from the assessment instruments as appropriate, and grade students in a scale ranging from a "I" (insufficient) through "D" (under development), C ("minimally acceptable proficiency"), C+, B ("expected proficiency") B+, A ("surpassing expectations") to A+, the highest grade. The grades are assigned by the advisor, and a student fails the capstone project if receives I or D in one learning object. Individual scores count about 70% for the final grade, while group results fulfill the remaining 30%. This strategy minimizes "free-riders" in the groups: students that do not contribute individually in a substantial manner and expect to profit from the group's performance as a whole.

## Capstone Project Implementation

In this section we describe the mechanics of the proposed capstone project.

### Learning activities

In order to prepare for the challenge of the capstone project students are required to attend weekly learning activities related to: project management, agile development methodologies, organizational culture, stakeholder analysis, project canvas, effective communication, and scientific methodology. Furthermore, teams participate in group meetings with different experts in areas of conflict management and corporate culture as the project evolves.

### Project Elicitation and Selection Process

Faculty members and staff from the careers service are responsible for identifying and contacting companies that may contribute with capstone project proposals. It is our experience that the personal involvement of well-connected faculty members, with professional as well as academic experience, is paramount to the generation of a quality portfolio of projects – even if the project elicitation effort demands faculty time that could otherwise be allocated to teaching or research.

Organizations are then invited to propose projects with genuine needs, where engineering students can develop solutions to real demands, putting their technical knowledge and skills into practice. Projects are filtered for suitability by a faculty and staff committee: suitable projects must have a scope that is limited enough so that students can grasp the complexity of the project, propose and implement viable solutions, while not being so close-scoped as to become a mere set of tasks proposed by the company.

The entire list of submitted projects is presented to the students through a capstone management system. Students choose at least 5 projects in priority order, based on their own interests and perceived competencies. The capstone faculty committee board then analyzes the student choices and assign them to groups of three to four students. Groups are assembled according to the student´s declared interest, technical profile, and the balance of competences required for the project.

Projects are often multidisciplinary, and so there are groups formed by students from different engineering programs. Students with different professional abilities may be assigned to the same project if the need arises. In certain situation where there is a project with many interested students, the GPA (Grade Point Average) can be used as a selection criteria.

Among the projects proposed by companies, there are also social projects proposed by non-governmental organizations; for instance, a social project was proposed by leaders of a poor community that would like to profit from recycling materials that would otherwise become a garbage accumulation problem in their area.

### Project Development

The time to develop the project is about 15 weeks (a regular academic semester). Students are required to have good discipline and proper time-management skills throughout the development of the project due to its short duration.

Students are free to choose the project management strategy most suitable for their project; they are also encouraged to learn from the project management strategy in use at the company where they will develop the capstone. Computer engineering projects traditionally use agile strategies, while projects with a more evident inclination towards Mechanical and Mechatronics Engineering tend to be adopt a wider range of alternatives.

All projects must pass through a design phase and deliver a solution that involves some level of a prototype. Laboratories on campus are available to the students for prototyping and development.

Teams are expected to visit their partner companies regularly to discuss the project, but also to participate in the corporate life and develop their soft skills (such as communication, negotiation and teamwork) in such environment. Friday is usually preferred by students as the day to visit the companies, as some of those are located far from the college campus; also, some companies prefer to allocate Fridays for side projects.

When a company is in other cities (and in extreme cases, several hours away by flight) presential visits are spaced further than once-a-week. Nevertheless, weekly communication by teleconferencing is still required in these cases, since verbal communication is part of the learning goals of the capstone project.

Teams should deliver three main reports:

- An initial planning document with a description of the problem, identification of stakeholders, literature review, and an initial schedule. This preliminary planning forces students to understand the challenge and devise, by themselves, the future steps needed to overcome it.
- A mid-semester progress report, which includes all information collected so far, an updated planning, and prototype details (if already developed).
- Final report, including all design and development details, lessons learned, shortcomings, and future work.

## Results

The first edition of the Final Engineering Project took place in 2018 with 53 students from Computer, Mechanical, and Mechatronics Engineering programs. After the first edition, 37 more students have finished their capstone projects. It is expected that approximately 150 students will engage regularly in the capstone project per semester (as the college is growing and has recently started accepting students each semester instead of once a year). After three capstone projects iterations, 26 projects were concluded. Interest from industry is high in this kind of proposal: 35 companies submitted projects with a total of 77 published proposals.

### Implementation challenges

Among the difficulties during the projects, team conflict was the most common[6]. Problematic teams were required to attend meetings with specialists in team dynamics, to mitigate conflict.

Some students also reported minor problems with companies and advisors; in these cases, the capstone program supervisor was involved to better understand the problem and help build a solution.

An issue arose regarding the placement of the capstone project within the duration of the whole program. Engineering programs in Brazil are typically five years long, and original plan was to have a two-semester capstone with a workload equivalent to two regular courses per semester. The first capstone iteration then took place in the second semester of the 4$^{th}$ year and the first semester of the 5$^{th}$ year, leaving the last academic semester for internship. But after the first iteration it was noted that students were applying for internships together with the capstone project, since many internships in Brazil require a one-year commitment from applicants (both semesters from the 5$^{th}$ year). The capstone experience was thus compromised: when faced with the dilemma of putting effort into their internships or the capstone, some students chose to neglect the latter. It was then decided that having the capstone with the same total workload (4 regular courses) but concentrated in only one academic semester would be a better solution. The capstone project was set to take plane in the second semester of the 4$^{th}$ year.

### Industry adoption issues

Since industry in Brazil is not accustomed to this kind of proposal, there was an effort on clarifying the capstone effort to company managers. Although the reception was good, companies were afraid about legal issues, privacy, and intellectual property:

- Since students are visiting regularly the company, there was a concern that this could be legally

identified as an internship, which has its own specific regulation. A contract was developed to make evident that this is not an internship, but a curricular component that students must fulfill. Nevertheless, it was decided to also pay life insurance for all students, which is something mandatory for internships.

- Companies were not sure about what kind of information they would need to disclose to students. Also, students may be required to walk around factories and other installations, and company secrets may be involuntarily revealed to them. A section was thus included in the students' contract about confidentiality and privacy; however, many companies also requested that students and advisors sign a separate Non-Disclosure Agreement, written by their own legal department.
- Intellectual Property was another issue to be negotiated. In the initial iterations of the capstone, it was decided that companies will retain all intellectual property rights within the scope of the project, but students can include in their curriculum vitae that they worked on the project.

A final issue is related to regulation for accreditation in Brazil, which requires that students produce a monograph at the end of engineering programs, and that the document must be publicly available[7]. Since there may be confidential information present in the capstone's final report, students and companies may need to edit the report to remove any confidential information, while retaining its documental nature, in order to publish the report.

## Conclusion

The first results show that students can answer companies' challenges with a high degree of quality. Feedback from companies are mostly positive and, in many cases, students were offered internships to continue working with the company.

From the industrial partner, apart from the recruiting aspect of the capstone, it has proved to be an opportunity to investigate whether new technologies are interesting and viable, whether a product design could be improved, or even solve an operational problem.

Evaluation of students' competencies and completion of learning goals was a contentious issue in some cases. Within the first iteration of the capstone (the two-semester implementation), some students failed and had to be allocated within new projects and new students for an extra semester, creating an unpleasant situation for all involved. With the change to a single-semester capstone this problem is mitigated. In the last semester it was also required from each student a biweekly short text describing recent progress; these reports serve as evidence of student evolution during the semester.

Some projects were deemed highly successful at completion; in this case they may continue for another semester, but this time as an elective course, if the company and the students show interest.

The design of the capstone project is evolving continuously. As a future effort we envision the creation of international teams, inviting foreign students and companies to participate. We plan to get more involved with the International Capstone Exchange Program[8] in order to facilitate the accomplishment of this internationalization plan.

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