Teaching human-center design to engineers: continuous improvement in a cornerstone course

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Introduction

This evidence-based paper describes the continuous improvement process of a first-year cornerstone (Project Based Learning) course which took place between 2014 and 2019 at an Engineering School. This improvement process has been based on data from the Department of Engineering Education, and the Instructor Evaluation Survey answered by students at the end of each semester. In this course, each semester, students follow a human-centered design process to understand a particular topic, find an opportunity for innovation, develop a solution, a prototype, and test it. This iterative process takes place during the first semester of engineering studies. Students need to identify a challenge from a particular topic. Topics vary each semester and go from Health to Firefighters. Based on students' performance through the years a three point criteria has been developed in order to determine the research topic for each semester. The final purpose of this article is to deliver guidelines to those who are interested in cornerstone courses. The article focuses on the continuous improvements made to a cornerstone course. These improvements are related to how to determine work topic, team composition, and team assessment methods for each semester.

Cornerstone courses are engineering design courses that provide first-year students with an early introduction to competences for solving real-world problems [1]. This type of course is usually taught using project-based learning (PBL) methodology, which introduces students at early stages to ill-structured problems. PBL methodology has proven to have several benefits for students by enabling them to generate original opinions and express individual standpoints, improve their active participation in self-learning processes, enhance communication skills, and promote critical thinking [2]. In the learning context of PBL, students develop authentic questions for problems that are situated within real-world practices [3], which leads to meaningful learning experiences [4].

Competences, such as critical thinking and communication skills promoted by PBL methodologies, are increasingly important for engineering practice. In the labor market it is expected that engineers not only work in technical contexts, developing solutions that meet clients' needs, but also perform their work through effective collaboration with others [5]. In engineering schools, these competencies are usually taught in the design courses at the final stages of the career (Capstone Course), which use project-based learning methodologies. However, students can be introduced to these competencies at an earlier stage through the first-year design courses (Cornerstone Course). The approach to these competencies at an early stage has several benefits, such as increasing students' interest in engineering, improving their retention, motivation, and performance in solving unstructured problems [1].

During their first semester Engineering students are usually faced with math and science courses such as: Calculus I, Chemistry, and Linear Algebra. For this reason, cornerstone courses present an opportunity for professors and their students to be in contact with each other from an early stage in their studies [6].

In today's globally competitive economy human-centered design processes contribute to innovations that reduce errors and improve acceptance from the community. Because of this it is relevant to develop design skills among undergraduate engineering students [7]. Understanding Engineering Design as "a systematic and intelligent process in which designers generate, evaluate and specify concepts for products, systems or processes whose forms and functions reach the objectives of customers or the needs of users while satisfying a set of restrictions" [6] students, in this cornerstone course, are required to solve an ill-defined problem by working in teams.

Wengrowicz, Dori, and Dori [2] argue that PBL courses, with a large number of participants, are challenging because they require students to be engaged and professors to be able to advise, monitor, and evaluate students' team performance. Since these types of courses are so beneficial there is a need to create guidelines for deploying cornerstone courses.

This article shows the lessons learned, in the period between 2014 and 2019, of a cornerstone course that is taught twice in each academic year at an engineering school with around 1100 students (800 in the first semester and 300 in the second semester). The goal of this case study is to describe assessment strategies and practices that can serve as guidelines for the following specific topics: criteria on how to determine each semester's working topic, team composition, and performance assessment methods at the group and individual level.

Cornerstone Course Description

The objective of this course is to identify and solve a real-world problem in a creative and innovative way. Table 1 presents a summary of this 16-week course.

Table 1. Cornerstone Course Summary

Teaching Methods	Project-based Learning. Lectures with class activities and workshops.
Course content	Engineering Design Process, Data analysis (qualitative and quantitative), Materials, Mathematical Models, Estimation.
Learning Outcomes	1. Solve a real-world problem (limited to a specific area of engineering design). Apply a user-centered design methodology in engineering in a creative and innovative way. Produce a device that responds to inequalities of a specific group in terms of social, economic and/or environmental vulnerability. 2. Articulate individual contributions to teamwork to develop a common project. 3. Develop safe and responsible behaviors in the laboratory, ensuring appropriate use of resources and the construction of an optimal product.
Assessment Methods	1. Individual assessment: Homework & exam. 2. Team assessment: Oral presentations of design process (research & prototype). 3. Peer assessment.
Evaluation Criteria	1. Professor: During the semester the professor assesses the design process. 2. Stakeholders: The final project deliverable is showed in a technological fair where stakeholders can assess them.

As stated in Table 1 this is a project based learning course, with individual and team assessments that involves peer assessment instances during the semester. During the semester students are expected to work in teams in order to solve a real world problem under a specific topic.

1- Choosing the topic for each semester

Choosing the topic carefully is relevant when using PBL. The projects should be based on problems that drive students to discover the central concepts and principles of a discipline [8]. The definition of the topic for students project must "be crafted in order to make a connection between activities and the underlying conceptual knowledge that one might hope to foster" [9]. This is usually done with a "driving question" [10] or an ill-defined problem [11]. PBL projects may be built around thematic units or the intersection of topics from two or more disciplines, that is not sufficient in itself to define a project. The questions that students pursue, as well as the activities, products, and performances that occupy their time, must be "orchestrated in the service of an important intellectual purpose" [10].

Based on students' performance and comments on the Instructor Evaluation Survey through the years a three-point criterion has been developed in order to determine the topic for each semester. These points are: boundaries of the topic, technological development in the area, and users accessibility. Table 2 shows some topics and their point matching.

Table 2: Topics and point matching

Semester	Semester / Topic	Boundaries of the topic	Users accessibility	Technological development
2/2013	Tools for market traders, construction workers, or street vendors	✓	✓	✓
1/2014	Health	Too broad	✓	✓
2/2014	Urban cyclists	✓	✓	There is too much technology in this area
1/2015	Teaching science in secondary education	✓	Students are minors. Working hours are the same as the university's	✓
2/2015	Fire Fighter	✓	✓	✓
1/2016	Reduce, Reuse, Recycle	Too broad	✓	There is too much technology in this area
2/2016	Public transport bus drivers	✓	✓	✓

1/2017	Inclusion in preschool	✓	Students are minors. Working hours are the same as the university's	✓
2/2017	Adapted sports	✓	✓	✓
1/2018	People with Down Syndrome and ASD	✓	Ethical concerns	✓
2/2018	Sports	✓	✓	✓
1/2019	Rescue teams (ambulance drivers, fire fighters, Andean rescue team)	✓	Ambulance drivers are always very busy	✓
2/2019	Small living spaces	✓	✓	✓

As shown in Table 2 in semester 1/2014 the course topic was Health. This topic was too broad which led to students becoming confused about what Health meant. They asked questions such as: Is healthy eating, Health? Who can be my user? Where do I start? All this resulted in a very rough start.

On the contrary, in semester 2/2014 the topic was *Urban Cyclists*. Students knew exactly who their user was and what Urban Cyclist meant. But, a lot of new technologies already exist in this area. Every time students came up with an idea, it already existed. The optimum technological development for the course topic must allow students to develop innovative solutions to problems that have not been solved yet.

In 1/2015 the topic was *Teaching Science in Secondary Education*. This topic did not comply with the second criteria: User accessibility. Students in Secondary Education are underage, which meant that our students needed to ask for parental consent to work with them. Schools' working hours are the same as in the university, which made it very hard to work. An anonymous student commented in the Instructor Evaluation Survey (2015) that it was: "A bad idea that this year's topic was related with schools. Going out to do surveys, interviews, and testing was very difficult. First, because schools are open at the same time we should be at the university, so to do our project we had to skip classes. And furthermore, it was very difficult to get permission to enter the schools."

In 2/2015 the topic was *Fire Fighters*. At the end of the opening class students knew who their user was, and where they should go to start their project. In Chile, there is not much technology available for Fire Fighters, and user accessibility is great. Fire fighters are most of the time at their work place.

In 2018, we had ethical concerns about how student would manage the work with people with Down syndrome or ASD due to their age and lack of experience in the subject. However, this concern was ungrounded because most of the students knew someone with ASD and/or Down syndrome so they worked with someone familiar to them, that they cared for and were absolutely engaged with their project.

2- Team Diversity and Composition

Classroom diversity encourages active thinking and intellectual engagement, which is beneficial for students and improves academic outcomes [12]. At the same time, perceived deep-level similarity has been associated with higher satisfaction and lower turnover intentions [13].

Table 3 shows the first semester's class composition at an Engineering School. As shown in Table 3, the number of students enrolled increased from 728 students in 2014 to 790 students in 2019. Consequently, the number of sections rose from 7 to 10 in order to reduce the number of students per section. The number of teams per section also increased from 10 to 12 aiming to reduce the number of students per team.

Table 3: First Semesters Class Composition

Year	2014	2015	2016	2017	2018	2019
Nº of Students	728	754	783	755	777	790
Nº Sections	7	8	9	9	10	10
Nº Teams per section	10	10	12	12	12	12
Nº Students per Team	10 or 11	9 or 10	7 or 8	6 or 7	6 or 7	6 or 7

There is no consensus on how many members should a team have. While Oakley, B., Felder, R. M., & Brent, R [14] recommend three to four people, Slavin, R.E [15] recommends teams of between two and six members. In this course students present their outcomes throughout the semester to the rest of the class (three instances during the semester). Each of these presentations take place during one week in periods of three 80 minutes class sessions. Because there are 12 teams per section it is possible to revise four teams in each of the 80 minutes classes. This leaves us with a fair amount of time to give feedback to the students. If teams were smaller this time would be reduced.

In our university, female students account for around 28% of the student body. Students that come from regions outside of the Metropolitan area account for around 26%, and students that enrolled through a special admission program around 15%. Less than 1% are foreign students. Because of this, we consider female students, students that enroll through a special admission process, and students from other regions as minorities. The Office for Undergraduate Studies puts together the work teams at the beginning of each semester, in order to avoid isolating students that belong to minorities. This is done by pairing students who belong to minority subgroups and placing them together on the same team. At the same time, students who come from the same high school are placed in different teams.

These criteria force students to engage with students coming from different backgrounds. At the same time they are not alone, giving them the possibility to perceive similarities within a diverse team.

To understand how team members contribute to their project a peer assessment methodology has been designed.

3. Team and Peer Assessments

Raban and Litchfield [16] stated that peer evaluation is an effective way for motivating students to participate in a team project and to engage more deeply in collaborative work. Individuals present themselves in a positive light when others can see their behavior because they do not want to be perceived negatively [17]. Team members are the ones who can best assess the dynamics of their teamwork and the degree to which each member contributes to their work. Consequently, peer evaluation can be an effective tool to provide information on the participation of each team member and their skills and weaknesses regarding teamwork [18].

Peer assessment can be formative, giving feedback to students, helping them improve their work, or a summative assessment, which allows them to adjust individual grades into group work [19]. Millis and Cottell [20] propose the following components to be assessed by peers: meeting attendance, task completion, contribution to the work, and/or support among team members.

This course measures students' performance at an individual and team level. At an individual level students face homework assignments and an exam. At a team level, students are required to present their progress throughout the semester. At the end of the semester there is a Technological Fair were teams exhibit their final prototypes and present their findings to stakeholders. Students are assessed during the semester in order to grade their individual contribution to the teamwork. Students assess their peers answering an online questionnaire. In order to pass the course students must obtain a passing grade at both individual and team levels.

To motivate team members and to improve students' academic performance a summative approach is pursued in this course. Table 4 and Table 5 show the peer assessment method implemented and student comments for 2014 and 2019 respectively.

Table 4: Peer Assessment Method and Student comments in Instructor Evaluation Survey 2014

<table>
<tr><th colspan="2">2014</th></tr>
<tr><td>Peer Assessment Method</td><td>Anonymous student comments in Instructor Evaluation Survey</td></tr>
<tr><td rowspan="2">Students assess their peers in the middle and at the end of the semester. The average grade given by their teammates represents 10% of the team level grade.

Students have an amount of points to grade their peers. The amount of points depends on the number of students per team. Students do not have to use all of their points.

Students grade their teammates answering the following question:

Considering Availability, Participation, Creativity and Effort. What grade would you give to your classmates?</td><td>"This is an instance in which rivalries and frictions within the group are generated. It's okay to discriminate between students who work and those who don't, but I think the number of points attributed to each group is too low.” (Student 1)</td></tr>
<tr><td>"It would be a good idea, in addition to grading with points, to add a mandatory comment justifying the grade. By doing this there would be a feedback and the grade will have a clear justification" (Student 2)</td></tr>
</table>

Table 5: Peer Assessment Method and Student comments in Instructor Evaluation Survey 2019

2019	
Peer Assessment Method	Anonymous student comments in Instructor Evaluation Survey
Students assess their peers after each of the course deliverables (4 times during the semester). The point average that a student receives will affect (increase, maintain, or decrease) the grade the professor gave the team on the respective deliverable. Students have an amount of points to distribute among their teammates. The amount of points depends on the number of students per team. Students do not have to use all of their points. Students grade their teammates answering the following questions: 1- Contribution to team meetings: Taking into account the availability and participation in team meetings and activities, how many points would you give your teammates? 2- Individual contribution outside of team meetings and activities: Taking into account if he/she performs the tasks assigned by the team within the stipulated period and if his/her work is adding value to the team, how many points would you give your teammates? 3- Promoting a constructive team climate by transmitting a positive and respectful attitude towards work and team. How many points would you give your teammates? 4- Mark in which of the following activities the student you are assessing participated. 5- If you want to add other activities or comments that justify your evaluation criteria this is the section to do it.	"Peer evaluation is an incentive for everyone to work." (Student 1) Student comments in the peer evaluation: "It should be noted that we all contributed to the final product. Ivo made the color design samples; Francisca also made the picture along with suggestions from Colomba, Mayron and Cristián. Cristián made the sample with the planimetry of the product and Pedro contributed with the wheelchair and the material to glue the sheet." (Student 2) "Nicolas and I made the slides, the script of the presentation and the prototype" (Student 3) ** We almost do not receive comments on the peer assessment methodology.

As shown in Table 4 and Table 5 the peer assessment method changed from 2014 to 2019.

In 2014 students had two peer assessment instances during the semester. Before the first instance they had two deliverables. Students complained that they were being peer-assessed based on the latest deliverable and that their average performance was not being considered. This issue was addressed by adding a peer assessment instance after each deliverable. In the week following each course deliverable students assess their peers by answering an on-line questionnaire.

In 2014 student assessed their peers by answering only one question. By doing so, students graded their peers according to their values. By answering a set of questions to assess their peers student's values are less important and they grade their teammates according to their actual teamwork skills.

Having comments on the work of each student is great for professors in order to understand what is happening concerning the individual contribution to the teamwork. If team members have problems with each other, the professor will have information regarding the team dynamic that otherwise he or she would not have had.

Conclusions

This case study described a cornerstone course with 1000 students enrolled per year referring to three important areas: Choosing a topic to work on, team composition when working with a diverse group and finally team assessment and peer evaluation.

Regarding the selection of the topic for each semester, the three point criteria developed (boundaries of the topic, users accessibility, and technological development in the topic area) has shown to be effective. Student engagement with the course improves when the topic meets these three criteria. The challenge is to determine, in advance, if the topic meets, or does not meet, these criteria.

Regarding team diversity and composition, students have been matched according to observable characteristics. A challenge is to include characteristics that are not observable, such as students with special needs (for example students from the Autism Spectrum Disorder).

Concerning team and peer assessment methods, having an assessment instance after each deliverable with a set of questions proved to be accepted by students. Having a comment section allowed professors to understand the dynamics of the team. A challenge is to encourage students to engage in peer feedback constantly, and not to wait for their peer assessment grades to understand their peers' perceptions of their work practices.

As part of a continuous improvement process this cornerstone course has been evolving during the past six years and will continue to improve as long as it is taught. Student demographic is changing. Student access to information and rapid prototyping technologies are increasing. All of these changes influence the way we teach Project-Based Learning courses and they should also be analyzed and taken into consideration as part of a continuous improvement process.

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