ANALYSIS OF STUDENTS' PERFORMANCE IN CAPSTONE PROJECTS

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ABSTRACT

After 10 years of having implemented the design-build project courses path according to the CDIO standard 5 at the ICT Engineering School of UPC in Barcelona, we have carried out an analysis of the students' performance in the 12 ECTS capstone project course performed in the 4th year of the bachelor and in which most of the challenges are set by external companies and institutions. In these 10 years, 1440 students have participated in 138 different projects. The course is called Advanced Engineering Project (AEP). This conference communication presents the results of the analysis of the individual students' performance according to different project features. We have considered the challenge source, (internal/external), the promoter type, the promoter involvement, for external promoters, the contact person profile, the result type, the degree of finalization, the size of the team and the term (Fall /Spring). The chosen performance index used for this study is the individual assessment result, which is quite integrative. About the Internal/External character of the promoters, there is a significant difference ($p<0.001$) in the AEP average of the individual marks of 0.42 points between projects with external promoters (8.68) and projects with internal promoters (8.26). Considering the type of promoters' significant differences ($p<0.05$) are found between projects proposed by companies and both the internal projects proposed by teachers and by research groups. The projects in which the main component was ideation or more ideation than technical performed better than the mostly technical projects (up to 0.92 points in a scale of 10, $p<0.001$). We have not found any significant differences due to the team size or academic term (Fall or Spring). The reasons for the observed differences are probably due to a different degree of motivation and also to a higher pressure when an external stakeholder is involved, although the differences are smaller than 1 point in a 10 points scale in all cases.

KEYWORDS

Capstone Project, Industry Involvement, Stakeholders, Performance, Standards: 5, 11.

INTRODUCTION

The demands for future engineers' competences have been highlighted since de past decades, both from industry and institutions like ABET (2017), CDIO initiative (Crawley et al., 2011, 2014), NAE (2004) and ENAEE–EUR-ACE® (European Network for Accreditation of Engineering Education, 2020), among others. What is expected from future graduates is far more than technical skills or "hard" engineering knowledge. Even though this is fundamental, it is not enough. Pippola et al., 2012 state that beyond having engineering core skills (which is a critical factor), it is needed to develop competences like creativity, communication, uncertainty management and business skills among others. This need of competences' development has widely been addressed from the academia by creating capstone design courses where final year students, as described by Dym et al. (2005), develop "real" project using their theoretical knowledge on a system level.

Following the CDIO framework (Conceive-Design-Implement-Operate), since 2012 at Telecos-BCN, the ICT Engineering School of UPC at Barcelona there were introduced capstone project courses named Advanced Engineering Projects (Bragós et al., 2010, 2012). It was observed that this notably improved some of the competences required by the industry (i.e.: problem solving, teamwork, project management, critical thinking, communication, among others). Beyond generic competences, it was also identified that specifically innovation related competences were also very relevant and demanded by industry and society (Lehman et al 2008) and needed to be further developed. With the aim of further developing innovation competences, in 2014, the Telecom Engineering School at UPC co-created with ESADE and IED the CBI (Challenge Based Innovation) Course, which students from UPC can take as an alternative to the "standard" capstone project (Hassi et al. 2016), working in multidisciplinary teams (engineering, design & business) to tackle complex societal challenges. and using CERN technologies. NESTA, as described by Chell & Athayde (2009) demands innovation skills like Creativity, Energy, Leadership, Self-efficacy and Risk propensity. These and other innovation competences can be developed through project-based learning and challenge-based learning (Charosky et al., 2021, Charosky & Bragós, 2021). Working with a clear project-based approach, inherently experiential (Kolb, 1984) tackling real life industry challenges or broader societal challenges, can help better equip engineering students with the skills and innovation competences demanded by the society.

It could be said that capstone projects became the standard in the past decades. They have evolved from "invented by faculty members" project topics to real industry challenges sponsored by companies or institutions (Dym et al., 2005). By working with Project-Based Learning in engineering higher education, with an active learning process and learning by doing approach (Johnson, 1999), students learn from real situations (Cazorla & De los Ríos, 1996). Cazorla et al. (2007), after 20 years of applying project-based learning in higher engineering education describe it as "the most adequate educational methodology for the development of competences, linking teaching with the professional sphere". Typically, these student projects in engineering education focus on solving a technical problem, working in non-multidisciplinary teams and following a "classical" product development approach described by Ulrich-Eppinger (2008). More recently, Challenge-based Learning has appeared as an alternative methodology to involve the real-world context in the project courses which focuses on identifying, analyzing and designing a solution to a sociotechnical problem going beyond the purely technical result. Typically, is approached in multidisciplinary teams and aims to reach "a collaboratively developed solution, which is environmentally, socially and economically sustainable" (Malmqvist et al., 2015).

There is a long tradition on capstone projects according to industry specifications and having external institutions as projects' stakeholders in the CDIO community. Design-Build projects (CDIO standard 5) are one of the most acknowledged ways of promoting the learning of skills of groups 2, 3 and 4 of CDIO syllabus. From the very beginning of the Initiative, there have been papers describing the cooperation between academia and industry. In the 1st annual CDIO Conference, Surgenor (2005), already described the involvement of industry in capstone projects at Queen's University in Kingston, Canada. Berglund (2007) also describes a 4th year multidisciplinary capstone project with industry involvement carried out at Chalmers. Thomson (2012) compares two projects performed at Aston University with different openness degree in the starting brief and project follow-up. Hallin (2012) discusses the role of customers of both the industry and the students, which have a different time-perspective. Metjoft (2015) discusses about the double role of Industry as an enabler and receiver. Tornqvist (2015) and Einarson (2015) describe the experience at their respective universities with project courses enabled by an external organization, Demola, which facilitates co-creation projects between university students and companies, either locally or internationally. More recent references describe the initiative to involve stakeholders at program level at DTU (Nordfalk, 2018) or the review of university-Industry collaboration in Europe and Asia (Rouvrais, 2020).

In this article, we analyzed the different capstone projects developed by the students in the last 10 years, since 2012, either project-based or challenge-based and studied the results of the teams and individual students' performance according to different project features. The main research question is if the challenges involving external agents would provide better students' performance and if there are other project features which would affect this performance.

STUDY FRAMEWORK

The implementation of the design-build project courses path, according to the CDIO standard 5, was completed 10 years ago in our School. Three courses were created: Introduction to ICT Engineering (2nd year, 6 ECTS), Basic Engineering Project (3rd year, 6 ECTS) and Advanced Engineering Project (AEP, 4th year, 12 ECTS). In the first two subjects, students work in small teams (3-5 students) on challenges of increasing complexity proposed by teachers and acquire the necessary methodology to undertake the challenges of the third one, AEP, object of this study. It can be assimilated to a Product Development Project (PDP) model. In this course, bigger working groups (8-12 students) undertake the design of a complete product or service, including its business model. The requirements and specifications of the product or service are generated, the block structure and the work packages are defined and then distributed among the subgroups of 2-3 students. They must design, implement and test the subsystems, integrate them, define a business model based on the product or service and perform the sustainability analysis. In the first years (2011-2014) the challenges of the AEP projects were proposed by the teaching staff. Since then, and building in the reported results and conclusions of the work of several CDIO institutions, cited in the last by one paragraph of the introduction, external agents were gradually incorporated (Figure 1) and currently, 7 out of 10 challenges are proposed by companies, hospitals, foundations or NGOs. Some challenges are reserved each semester for strategic projects such as Formula Student Driverless, nanosatellites or 5G research. This subject is compulsory and 1440 students have passed through it who have worked in 138 different projects, being 81 of them proposed by external agents.

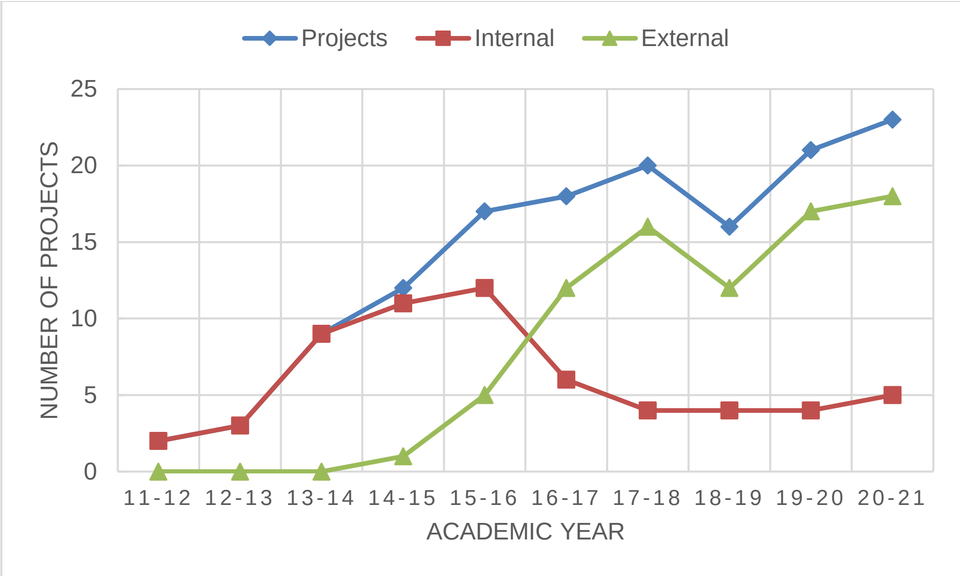

Figure 1. Time evolution of the EP capstone projects along 10 academic years (2011-2012 to 2020-2021) and type of promoters (internal/external)

Some examples of project challenges are: image processing software for rehabilitation of facial paralysis due to facial nerve injury, human-machine interface techniques for car cockpit, development of sensors for 3D printers, blockchain-based payment distribution system in the music industry or low-cost IoT sensor system for detection of irregular discharges in wastewater.

METHODS

The object of the study is the performance in the AEP capstone course project of the 1440 students that have participated in 138 different projects in the 10 years since the first implementation of AEP (academic years 2011-2012 to 2020-2021). The average team size is 9.2 students, with a minimum of 4 and a maximum of 20 but only 12 out of 161 have been smaller than 7 or bigger than 14. There are more teams than different projects because in some cases, two teams have performed two replicas of the same project. The course takes 15 weeks and is performed every term, so twice per academic year, except in the first two years.

The learning outcomes of the course are mostly the ones of the involved generic skills, most of them related with the CDIO syllabus skills group 4 (Innovation and Entrepreneurship, Societal and Environmental Context, Ability to Conceive, Design, Implement and Operate Complex Systems in the ICT Context) but also Oral and Written Communication and Teamwork. Although the individual final grade is not the only valid metric to assess the performance in the course, we have chosen it as performance index for this study because of its integrative character. According to the learning outcomes of the course, the project supervisors assign a team mark, which reflects the assessment of the process (50%) (Preliminary and Critical Design Review, team dynamics) and the final result (50%) (Solution Technical Performance, Business Idea, Final Report, Final Presentation and Video). The individual marks are obtained from this team mark after applying a triple modulation (30% max): The Supervisors' Assessment of the individual performance, the Team Leader assessment (batch of points) and the Peer Assessment using a 10 criteria rubric. Therefore, the final individual marks are quite integrative of several aspects. The average of the individual marks is 8.44 in a scale of 10, with a standard deviation of 1.17.

The features and categories which have been taken into consideration to classify the projects are displayed in Table 1:

Table 1. Project features and categories

Features	Categories and ranges
Promoter type	Internal / External
Promoter type (detailed)	Teacher / Research Group / NGO / Hospital / Company /Institution (e.g. CERN, City Council)
Promoter involvement	Sponsor/Stakeholder
Contact type	Management/Technical/User/Teacher)
Result type	ideation (1) to pure technical (5)
Degree of finalization	Incomplete , functional test, test with users (1-5)
Size of the team	4-20
Term	Fall / Spring

About the promoter type, a higher-level category (Internal/External) has been added. The two kind of promoters which belong to the University staff (Internal) are Teachers and Research Groups. The difference among them is that Research Groups propose challenges that are coherent with their research activity. They are limited to topics that are considered strategic by the School (Nanosatellites, 5G, Autonomous Vehicle, Biorobotics) as fields in which there is interest in promoting specific skills for the graduate students. On the other hand, the category "Teachers" includes projects whose challenge was defined by the teaching staff but not as a part of their research activity but trying to define real world challenges according to their technology transfer experience. This modality was mainly used in the first years, before having enough external institutions engaged. In addition to the internal/external character, other differences can be induced by the type of contact person (technical or closer to the management or a final user) or the term (semester) or the team size. The difference between sponsor and stakeholder is that the first one is more involved while the second one may just behave as an external observer.

For the statistical analysis, the hypothesis that the marks in the different feature categories are different has been tested using the t-test for comparisons between two categories and the Anova test for comparisons between more than two categories. Depending on the statistics of the data (gaussian or not gaussian, equal variance or not), the suitable kind of test (standard t-test, Welch, Mann-Whitney) was applied. In the boxplot graphs depicted in the results section, the grey box contains the 50% of the values and an inner line shows the median. Then the upper and lower tails represent the range of the 95% of the values and the outliers are marked as individual symbols. The tool used for the analysis was SigmaPlot (Systat Software Inc, UK).

RESULTS AND DISCUSSION

In this section, the results of the more representative cases are displayed and the statistically relevant differences are highlighted, discussing the possible causes when there is an identified background.

The differences among AEP marks between the two terms (Fall and Spring) are very small (0.01 points), and not significant ($p=0.157$). Considering that the students that follow the progress of their cohort perform AEP in the Fall term, we expected a higher difference. Nevertheless, the delay in the progression of students can take more than one semester and there would be diffusion in the composition of the actual cohorts.

About the possible incidence of the team size, the correlation analysis shown no correlation among the team size and the individual marks. We were expecting a kind of optimal size for the teams to generate the better results (up to the extent that the results are reflected in the mark) but apparently there is no correlation at all.

About the promoter type (Internal/External), there is a significant difference ($p<0.001$) of AEP average of the individual marks of 0.42 points between projects with external promoters (8.68) and projects with internal promoters (8.26). If we consider the detail in the type of promoters (Figure 3), the significant differences ($p<0.05$) are found between projects proposed by companies and both the internal projects proposed by teachers and by research groups. This can be due to a higher motivation in the first ones but also to a different kind of expected results. The motivational character of having external stakeholders is consistently mentioned in the reflection document that is included in the projects' final report and in the oral feedback received by the supervisors. We didn't perform, however, a systematic analysis of these reports looking for a confirmation of this hypothesis and, therefore, this conclusion can be considered speculative.

Among the external promoters, the ones that show more differences with the internal project results are the industrial or services companies. The projects for NGOs show lower results but there have been few of them and the interaction has not been as good as with other stakeholders. It has been observed that NGOs, foundations and some small companies have different expectatives than regular companies with a higher degree of professionalization. These last ones understand clearly what they can expect from a capstone project performed by 4th year students and play their stakeholder role collaborating with the educative function of the course. They are more interested in having students with the suitable learning outcomes and in having more chances to hire some of them than in the project outcome. On the other hand, and despite our efforts in managing expectatives, NGOs, foundations and some small companies, even hospital departments are more interested in having a result as close to a final product as possible and this affects the interaction with the students and their motivation and commitment.

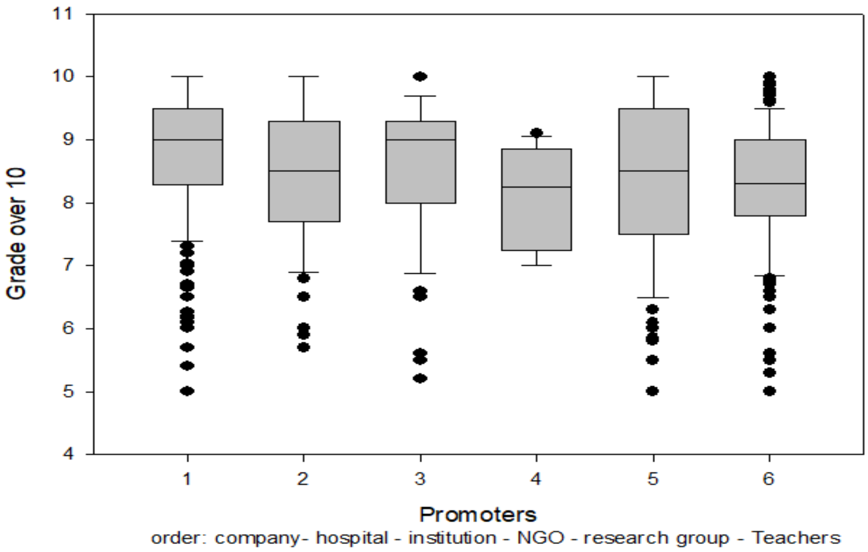

Figure 2. Boxplot of the individual AEP marks according to the challenge promoter type.

If we consider the type of results, it can be seen in Figure 3 how the more abstract projects obtain higher average marks than the purely technical ones. The categories "only ideation" (9.26) and "more ideation than technical" (9.09) provide significant higher marks than "more technical than ideation" (8.80) and "purely technical" (8.34). The projects which include some kind of creative phase at the beginning or which have more degrees of freedom obtain better marks than the projects that are purely technical, which start from requirements and specifications already set. Very likely, if the students feel themselves as owners of the solution, the motivation would be higher.

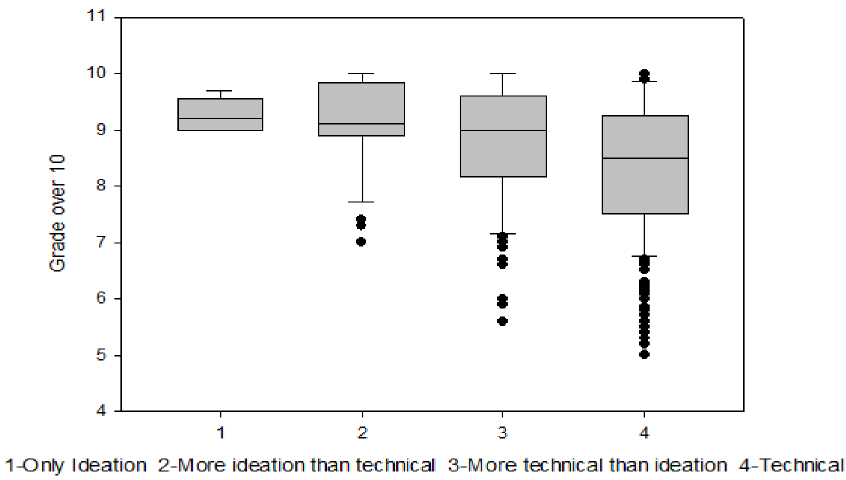

Figure 3. Boxplot of the individual AEP marks according to the type of project results

Even if the promoter is an external institution, the contact person or persons are in some cases engineers (technical) and in some others managers and even users. There are significant differences among some of them (Figure 4). The cases in which the contact person was a pure manager, the marks have been lower than the others although the high dispersion in this category limits the statistical significance of the differences. The combination of management/user (typical of hospitals) shows to be significantly higher (9.1 points) than most of the others and, as it could be expected, the results when external technical staff are involved (8.7), are significantly higher than when the stakeholder is a teacher (8.3) ($p<0.001$). Again, having an external stakeholder is a key factor.

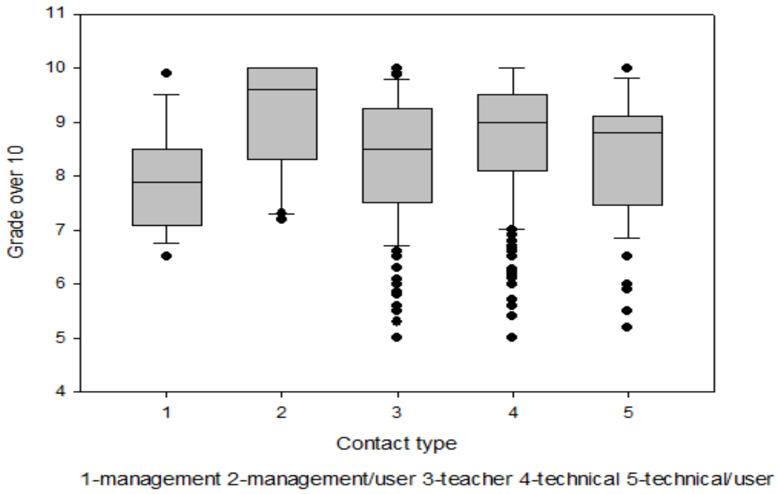

Figure 4. Boxplot of the individual AEP marks according to the contact person type

About the finalization degree (Figure 5), from the few projects that have not been able of integrating the parts to projects tested with real users, the average marks show an ascending progression with significant differences ($p<0.05$) in all cases.

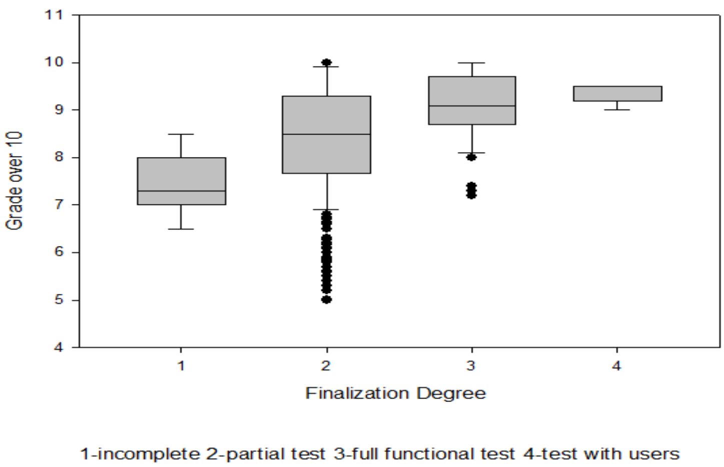

Figure 5. Boxplot of the individual AEP marks according to the project finalization degree.

The finalization degree can be due to incidences or to projects that start at a different readiness level and then are expected to reach different finalization degrees. We acknowledge that the Finalization Degree cannot be considered an independent variable but we found that the projects which are able to provide full functional tests and even tests with users generate a more comprehensive experience which would drive to better results, again probably due to a higher motivation than the projects that design and build a system or service which is not complete.

In courses such as these, the team supervisor may play a substantial role in the team's results, both because his/her ability to motivate the students' team and also because of his/her personal role as evaluator. There are more than 25 supervisors involved in this course, among the two terms. They work in pairs (each project has two supervisors) and, at least one of them has been involved in internal projects before supervising projects with external stakeholders. Therefore, they may appreciate the differences and take them into account for the assessment. Every term, before publishing the final assessment, there is a coordination activity to discuss the marks assigned to each team/project in order to justify the fairness of the mark differences among them.

CONCLUSIONS

The more significant differences between PAE marks according to the PAE project features are that there is a difference of 0.42 points between projects with external promoters and with internal promoters probably due to a higher motivation in the first ones, being the industrial or services companies the external institutions which provide better results. The projects which have more degrees of freedom obtain better marks than the projects that are purely technical, which start from requirements and specifications already set. Also, the projects which are able to generate a testable result and in which the interaction with the students is done by professionals with a technical/user profile or management/user profile obtain better results also probably due to a higher motivation and engagement. Nevertheless, these differences are not really big, less than one point on a scale of 10 in all cases, which would mean that the internal projects are also playing a good role as learning experience.

According to the students' feedback, the reasons for the observed differences are probably due to a different degree of motivation and also to a higher pressure when an external stakeholder is involved, although the few internal projects are carefully chosen and the topics are quite appealing.

The AEP course was the first capstone project course we implemented in our curricula, more than 10 years ago. Therefore, it has been a field for prototyping and testing active teaching and learning modalities. In the last three years, we started new bachelors (Data Sciences and Engineering and Electronics Engineering) and a Master (Urban Mobility) and we introduced that kind of courses in them, with external stakeholders from the very beginning as a requirement.

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