CORRELATION STUDY BETWEEN THE PERFORMANCE IN DIFFERENT ENGINEERING COURSES AND PROJECT-BASED COURSES

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ABSTRACT

In a previous study, already published (Bragós, 2022), we analyzed the correlation between the University access mark to the engineering studies with the grades obtained in project-based courses and in non-project-based standard courses. A lower correlation with the capstone course performance (R=0.3) than the one obtained with the average of the other courses (R=0.6) was obtained. Probably as a result of the fact that a different kind of skills are promoted in these courses. In this paper, we have changed and extended the scope of the correlation study. We used as a reference of the students' performance index the individual average marks in the 1st year basic courses. Then we obtained the correlation with different categories of courses of our engineering program: theoretical/practical, mandatory/elective, by disciplines, and the Project-Based Learning (PBL) and Product Development Project (PDP) courses. This is, using internal indicators instead of the access mark, which has an external origin, and improving the granularity of the study. We have analyzed four consecutive cohorts that have completed a coherent set of subjects, n=762 students. We have classified the subjects (40 courses per student in average) in the categories aforementioned. They are compared with the performance in two "classic" PBL courses and a capstone PDP course. There is also a final Engineering bachelor thesis which is usually performed individually in companies or research labs. The very abridged results of the study display differences even higher that the ones obtained with the access mark. The three groups of non-project standard courses show a higher correlation among them (R=0.84 Basic to Mandatory-Disciplinary; R=0.69 Basic to Elective-Disciplinary) that when comparing the Basic courses with the PBL courses (R=0.59) or with the capstone PDP course (a very weak correlation with R=0.26). The complete set of cross-correlations among the categories is displayed in the paper. Like in the study about the correlation with the access mark, the main conclusion is the evidence that there is a remarkable set of students which have difficulties in the standard courses, with a higher analytic content but can perform very well in the project-based courses. Therefore, a different kind of skills are promoted in these courses. This is, in our opinion, a positive result because these students can find a place to stand out. It enhances their self-confidence and their perception of a potentially good performance in their future career.

KEYWORDS

Project-Based Learning, Product Development Project, Correlation Study, Standard: 5

INTRODUCTION

Project-Based Learning and, specifically, Product Development Project (PDP) capstone courses where student teams develop "real" projects using their theoretical knowledge on a system level (Dym, 2005), (Hoffman, 2014), are considered among the more successful tools to promote the personal, interpersonal and professional competences required by the different accreditation agencies and worldwide initiatives that have defined lists of skills. The CDIO community has a long record of capstone projects with external stakeholders. 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 (Crawley, 2011). From the very beginning of the Initiative, there have been papers describing the cooperation between academia and industry. 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. Mejtoft (2015) discusses about the double role of Industry as enabler of collaborative projects and receiver of the developed results. More recent references describe the initiative to involve stakeholders at program level at DTU (Nordfalk, 2018), the review of university-Industry collaboration in Europe and Asia (Rouvrais, 2020) or the use of Communities of Practice to guide and support Capstone supervision (Topping, 2022).

There are evidences from observation by faculty members and from feedback from students that the kind of skills promoted in these courses require a different learning attitude. Being successful in analytic courses is not a guarantee for succeeding in experiential courses. Conversely, students which are not so-successful in analytic courses may have an outstanding performance. So, the research question was to determine if the grades of the individual students in different kind of courses (theoretical, practical, mandatory, elective, different disciplines, PBL, PDP) would correlate in a different way among them. We took as primary variable the grade of 1st year basic courses (all of them with strong analytical contents and methodology).

In Spain, as well as in other European countries, the students obtain a University access mark by averaging the grades of the two last High School years and the result of a discipline-oriented exam, which is performed nationwide. This access mark is used to rank and select the students that intend to enroll a given bachelor in a given institution. In a previous study, already published (Bragós, 2022), we analyzed the correlation between the University access mark to the engineering studies, a usual a-priori success estimator, with the grades obtained in project-based courses and in all non-project-based standard courses. The results displayed a lower correlation with the capstone course performance (R=0.3) than the one obtained with the average of the other courses (R=0.6). Not only the correlation with the access mark in the PDP capstone project courses is lower but the prediction interval is also different. While it is almost impossible that a student with a low access mark obtains an outstanding average mark in the bachelor and vice-versa, there are students with a low access mark which have an outstanding performance in the capstone project, which is very good for their self-confidence and self-efficacy, and this is probably a result of the fact that a different kind of skills are promoted in these courses.

As a result of this first study, we realized the need of determining if this correlation would be similar comparing the results of different categories of courses of our engineering program and the PBL and PDP courses, designed and implemented according to the CDIO Standards 4 and 5. This is, using internal indicators instead of the access mark and improving the granularity of the study. The academic achievement previous to the University studies is usually considered a good a priori estimator of academic success in higher education. Newman-Ford et al. (2009) relate it with the success in the first-year attainment and in the drop-out rate. Putwain et al. (2013) studied its effects in academic self-efficacy. The university access mark, however, can be biased by the kind of school in which the students had the secondary education. The grades of the 1st year course are, however, obtained in a homogeneous way. The aim of this communication is to present the results of this analysis. A similar study, performed in the UPC Architecture School was reported by García-Escudero et al. (2022), which also revealed low correlation between analytic skills and performance in project courses and identified clusters of homogeneous courses through correlation of grades as result.

METHODS

The previous study (Bragós, 2022) included the students of 10 academic years (2011-2021). Along these years, there were several slight changes in the curricula. In order of having a coherent set of courses to study the cross-correlations among them, we have limited the scope in the study we are reporting to 4 academic years, 2015-2016 to 2019-2020. We have included only the 762 students that have completed all the same courses (except the electives) including the bachelor thesis.

Assuming the limitations of the individual final grade as a valid metric to assess the performance of the student in a subject, we have chosen this performance index for this study because of its integrative character in the case of the project-based courses (PBL and PDP). 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. We have analyzed four consecutive cohorts that have completed a coherent set of subjects, n=762 students. We have classified the subjects (40 courses per student in average) in the categories aforementioned.

The Telecommunications Engineering Bachelor Program is distributed along four years (8 terms) as shown in Table 1, where all the subjects are depicted. To analyse the related behaviour between these subjects and the PBL and PDP ones, different classifications have been made, according to the contents and/or the kind of knowledge they contain. The parameter to be correlated is the individual average mark in each of the subject's group. Attending to this, three different classifications have been made. The first one, named Classification 1, groups the subjects which are considered Basic, containing all the first-year subjects, Mandatory, containing the disciplinary second- and third-year mandatory subjects, and Elective, including only Major Elective, containing part of the third- and fourth-year ones. The second classification, Classification 2, considers if the subject has scarce practical contents, and then it is considered as Theoretical or if it has medium to high practical contents, and then it is marked as Practical. And finally, Classification 3, groups the subjects in the ones that have high math and/or physics contents, naming them Science, and the subjects related to the different majors: in Electronics, Telematics/Networks, Telecommunication Systems and

Audiovisual Systems and Signal Processing. It is important to clarify that almost all courses included in these categories, except the PBL and PDP ones, have a high level of abstraction and include mathematical analysis methods which are assessed. The transversal elective courses which are non-disciplinary, have been excluded.

Figure 1 displays all this information as follows. Classification 1 is shown marking the subjects in black squares. Classification 2 is shown by marking P on the subjects that have been considered as highly Practical and finally Classification 3 uses the subject colour to indicate the essence of the subjects, whether they are pure scientific based (mathematics, physics in cyan on Figure 1) or they contain more specific disciplinary knowledge, namely related to electronics (green), telecommunications systems (violet), telematics/networks (pink) or Audiovisual Systems and Signal Processing (yellow). All the Elective block is coloured in different colours as it will depend on the chosen major and information about whether they are theoretical or practical is not depicted on the Figure for the sake of clarity. The subjects marked in Orange are the PBL and PDP ones, and there is always a final bachelor Thesis (TFG). In the Figure 1, transversal electives and practicum are also shown, although they have not been considered for this study.

Table 1: Telecommunications Engineering Bachelor Program depicting the different group of subjects considered in each classification. Namely: Classification 1 distinguish the subjects in black squares. Classification 2: marking with a P the subjects that have been considered as highly Practical. Classification 3: uses the subject colour to indicate the essence of the subjects: Cyan: scientific based (mathematics, physics); Green: Electronics; Violet: Telecommunication systems; Pink: Telematics/Networks; Yellow: Audiovisual Systems and Signal processing.

Term	**Telecommunications Engineering Bachelor Program**				
4B	Elective / Practicum	Elective / Practicum	**TFG (Bachelor Thesis)**		
4A	Elective / Practicum	Major Elective	Major Elective	**PDP**	
3B	Major Elective	Major Elective	Major Elective	Major Elective	Economy and Management (P)
3A	Microprocessor Systems Design (P)	Radiation and Propagation	Data Transmission	Audiovisual and communication signal processing	**PBL**
2B	Electronic Systems (P)	Electromagnetic waves	Telematic applications and Services	Communication Introduction	Audiovisual Processing Introduction
2A	Digital Design (P)	Electromagnetism	Systems and Signals	Statistics and Probability	**PBL**
1B	Linear Circuits and Systems (P)	Introduction to Telematic Networks	Object Oriented Programming (P)	Telecommunications Mathematics	Vectorial Calculus
1A	Electronics Fundamentals (P)	Physics Fundamentals	Programming Fundamentals (P)	Linear Algebra	Calculus

For each combination, the Pearson's R correlation coefficient was obtained and the linear regression between each indicator and the access mark was represented, including the +/- 95% prediction interval around the regression line. The analysis tools we used were Matlab

(The MathWorks, Inc., Natick, Massachusetts, United States.) and SigmaPlot 14.5 (Systat Software, UK).

RESULTS

Correlation between the marks obtained in the different groups of subjects with the marks obtained in PBL, PDP and the TFG has been made for the three classifications. Figure 1 shows the results of the correlation matrices for the three classifications.

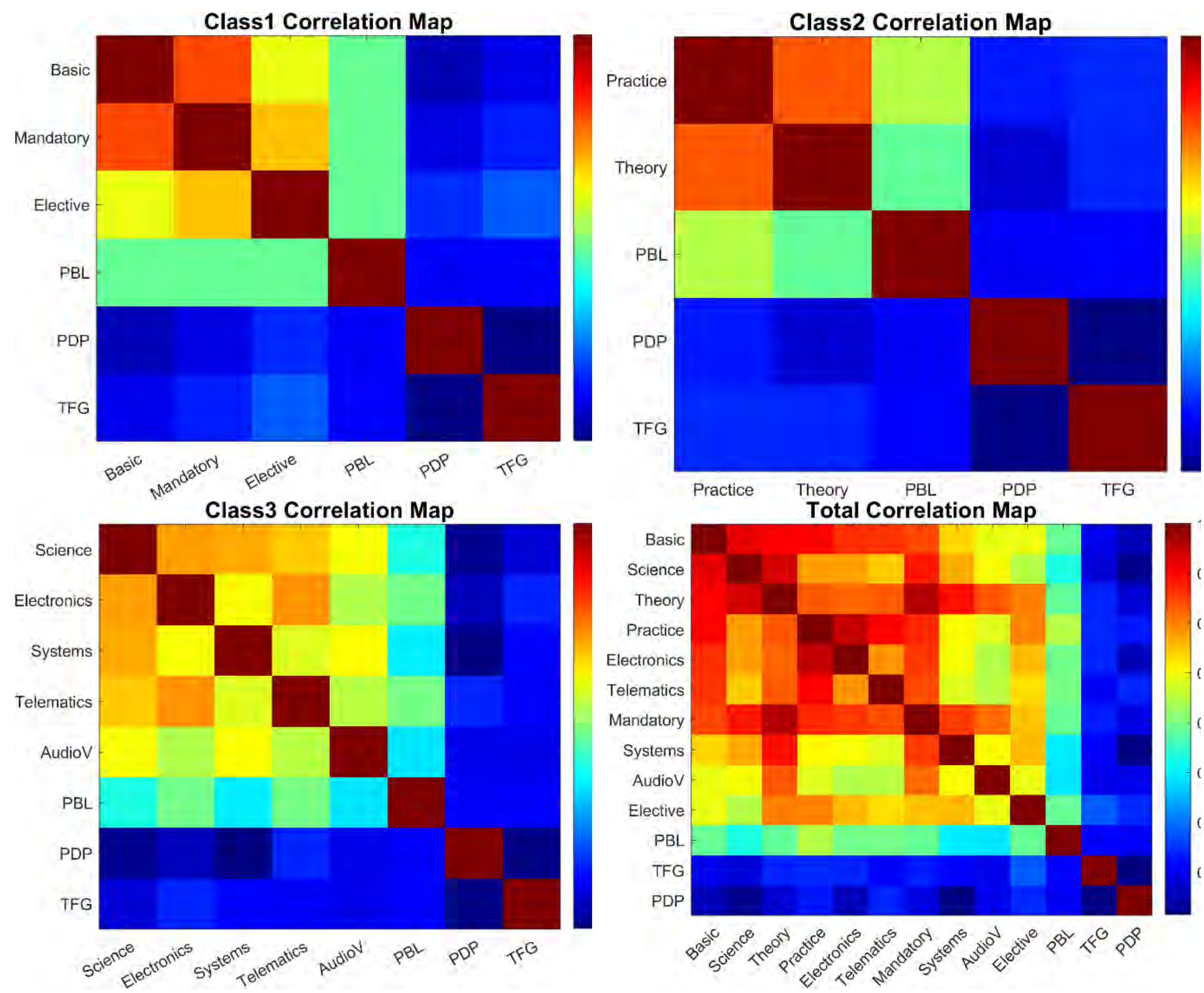

Figure 1. Correlation maps showing the marks correlation coefficients of the groups of subjects with PBL, PDP and TFG, in three classifications: 1) Classification 1, up-left: Basic, Mandatory and Elective subjects; 2) Classification 2, up-right: Practical and Theoretical subjects; 3) Classification 3, bottom-left: Science, Electronics, Systems, Telematics/Networks, Audiovisual Systems and 4) bottom-right: All the groups together. Note that there is symmetry in each of the matrices.

The first classification shows that the Basic block of subjects is in good agreement with the Mandatory block and it is also highly correlated with the Elective one. In general, there is a modest correlation of any of the Classification 2 groups with PBL subjects and it is almost null with PDP and TFG.

Classification 2 shows that practical and theoretical subject groups are highly correlated among them, slightly correlated with PBL subjects and, as in the previous case, there is a very low correlation with PDP and TFG.

Classification 3 shows that there are some subject categories that are more correlated in terms of the obtained marks, with the scientific ones, like Electronics, whereas others, like Audiovisual Systems and Signal Processing are less related. Electronics and Telematics/Networks slightly correlate with PBL subjects and, as in the previous analysis, none of the groups correlate with PDP nor TFG.

Finally, a total comparison of the different classification is shown. Table 2 shows the same information than Figure 1.4), in order to give all the exact data and facilitate a “one-glance” summary. There is an important remark in these results, as some of the subject groups include shared subjects, and this will alter the results, this is the case of Basic, Science and Theoretical subjects, as an example. The correlation matrix shows high correlation between the marks obtained in Science, Basic, Theory, Practice, Electronics, Telematics and Mandatory subjects, whereas there is a medium to high correlation between the marks obtained in Telecom Systems, Audiovisuals and Electives. As in the previous results, there is a medium correlation of most of the subject groups with PBL subjects, while the correlation with PDP and TFG remains very low.

Table 2. Correlation R values between all the different classifications average marks.

R value	**Basic**	**Science**	**Theory**	**Practise**	**Electronics**	**Telematics**	**Mandatory**	**Systems**	**AudioV**	**Elective**	**PBL**	**TFG**	**PDP**
Basic	1,00	0,92	0,90	0,90	0,86	0,86	0,84	0,74	0,69	0,69	0,59	0,30	0,26
Science	0,92	1,00	0,93	0,78	0,78	0,74	0,88	0,77	0,70	0,65	0,53	0,28	0,23
Theory	0,90	0,93	1,00	0,83	0,82	0,83	0,96	0,89	0,83	0,80	0,58	0,34	0,28
Practise	0,90	0,78	0,83	1,00	0,95	0,90	0,87	0,71	0,68	0,80	0,65	0,34	0,33
Electronics	0,86	0,78	0,82	0,95	1,00	0,79	0,86	0,70	0,64	0,76	0,60	0,34	0,26
Telematics	0,86	0,74	0,83	0,90	0,79	1,00	0,84	0,68	0,65	0,73	0,60	0,30	0,34
Mandatory	0,84	0,88	0,96	0,87	0,86	0,84	1,00	0,85	0,82	0,75	0,59	0,33	0,29
Systems	0,74	0,77	0,89	0,71	0,70	0,68	0,85	1,00	0,70	0,76	0,50	0,31	0,22
AudioV	0,69	0,70	0,83	0,68	0,64	0,65	0,82	0,70	1,00	0,69	0,49	0,30	0,30
Elective	0,69	0,65	0,80	0,80	0,76	0,73	0,75	0,76	0,69	1,00	0,59	0,38	0,34
PBL	0,59	0,53	0,58	0,65	0,60	0,60	0,59	0,50	0,49	0,59	1,00	0,31	0,30
TFG	0,30	0,28	0,34	0,34	0,34	0,30	0,33	0,31	0,30	0,38	0,31	1,00	0,21
PDP	0,26	0,23	0,28	0,33	0,26	0,34	0,29	0,22	0,30	0,34	0,30	0,21	1,00

To have a more visual and quantitative information, some of the correlation coefficients have been displayed in bar plots. Figure 2 shows these results.

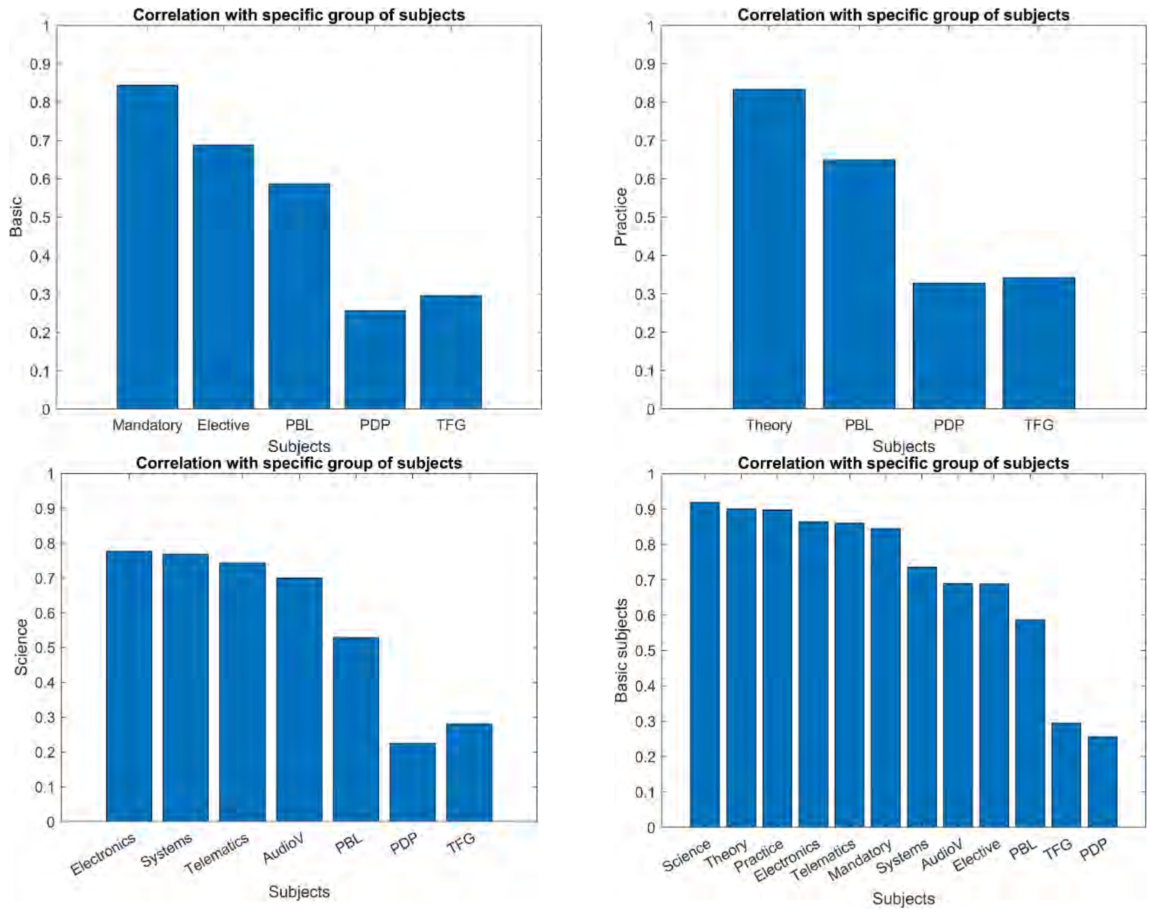

Figure 2. Correlation coefficients of the marks: 1) Basic subjects correlated with Classification 1, up-left; 2) Practical subjects correlated with Classification 2, up-right; 3) Science subjects correlated with Classification 3, bottom-left; and 4) Basic subjects correlated with all the subject groups.

As it can be observed in Figure 2, the marks obtained in the Basic group highly correlate (R=0.84) with the marks obtained in the Disciplinary Mandatory group, the correlation with the Elective group is R=0.69 and it is R=0.59 with PBL subjects. The correlation with PDP and TFG is R=0.26 and 0.30, respectively. The practical subjects' marks are highly correlated with the theoretical ones (R=0.83), while their correlation with PBL subject marks is R=0.65, whereas the correlation with PDP and TFG marks is R=0.33 and R=0.34, respectively. Finally, just comparing the Science related subject marks with the other contents, the higher correlation is found with the Electronic subject marks (R=0.78), followed by the Telecommunication Systems subject marks (0.77), Telematics/Networks (R=0.74) and Signal Processing and Audiovisual Systems (R=0.70). The correlation with PBL, PDP and TFG subject marks is R=0.53, R=0.23 and R=0.28, respectively. The last part of Figure 2, at the bottom-right, shows the correlation of the Basic subject marks with all the other categories. The bar plot has been ordered form higher correlation values (R=0.92), to the lower correlation value (0.26), obtained for the PDP subject.

In order to better interpret these correlations, the following figures display the linear regression between the individual basic courses' marks (x axis) and the other groups individual marks (y axis). The thick red lines display the linear regression line and the 95% confidence interval of the regression while the dashed red lines indicate the +/- 95% prediction interval of the indicator if the regression is used for this purpose. All graphs have the same axes scale in order of making easier their comparison.

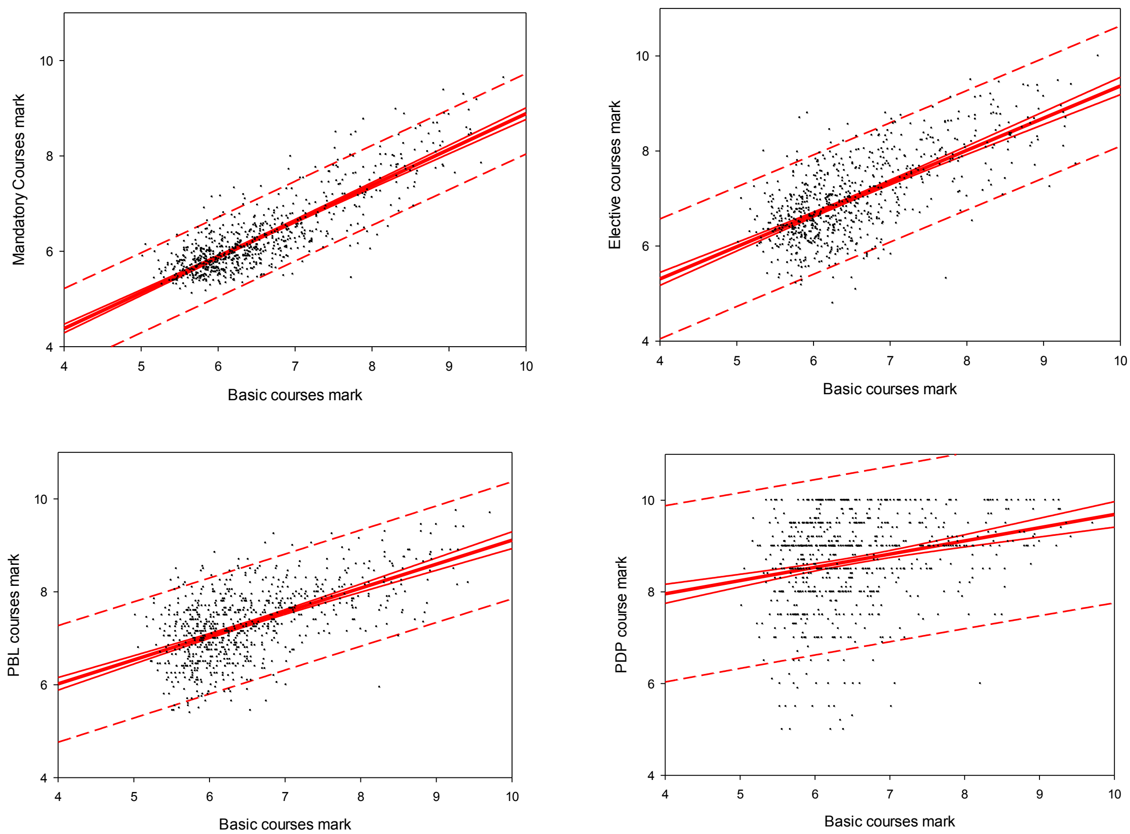

Figure 3. Correlation Basic courses mark – Disciplinary Mandatory courses mark (top, left); Correlation Basic courses mark – Disciplinary Elective courses mark (top-right); Correlation Basic courses mark – PBL courses mark (down-left) and Correlation Basic courses mark – PDP course mark (down, right).

As we can see, in addition of the correlation value, we can observe that the probability that a given student with low average marks in the basic courses reaches good marks in the disciplinary mandatory or elective courses is almost null, and vice-versa. It is a bit higher in the PBL courses. In the PDP capstone course, however, there are a lot of students with low performance in the basic (more analytical) courses which are able of obtaining a good and even outstanding mark.

DISCUSSION

As explained before, the Telecommunications Engineering Bachelor program is mostly oriented to acquire deep theoretical knowledge by means of master classes with a high mathematics and physics contents. Most of the subjects of the program, even the Elective and Practical ones are based on this philosophy. PBL subjects, although partially guided, are project based and mostly intended to acquire generic skills, but the challenges are defined by the supervisors in order to also acquire some specific disciplinary knowledge. The students can interpret them as a practical course but not so different to other courses with laboratory activities. They are intended to be training activities to face the PDP course in the fourth year.

This PDP capstone course includes a complete product or service development and demands very different skills than the ones asked in the rest of subjects. This subject proposes different projects, defined by the industry or other external institutions. The students make groups of 7 to 12 people to develop the chosen project and they have freedom to choose the kind of project. There is scarce guidance in terms of identifying the real and feasible goals of the project, the best way to solve them, how to face the challenge and identify risks, and develop a contingency plan. They also distribute the time, and coordinate the tasks between the teammates. Some of these skills have been worked in practical and PBL subjects. But this PDP subject is the first one that faces all these challenges. At the same time, it is the first time that the students really choose the contents of the challenge among 8-10 alternatives, and this is highly motivational.

The results lead to some interesting conclusions. It is remarkable the high degree of correlation of the theoretical and practical subjects. As described before, the program of the bachelor is highly demanding and has a very theoretic orientation. So, even the so-called practical subjects, are in fact a mixture of theory and practice, and even the practical part, includes deep calculations and many times written exams to score for this part. It is also interesting that the group of subjects that show a best agreement with the science subjects are the Electronics ones. It has been observed a highly vocational profile in these students, who usually look more into the practical approach of the problems. This seems somehow to correlate with their scores in mathematics and physics subjects.

As for the core of this study, the results of correlating the average marks obtained in any of the master classes with PBL and PDP are clear. All the subjects group marks mildly correlate with PBL subjects, but none of them correlates with PDP in a significant way. The practical, Electronics and Telecommunications and programming subjects' marks correlate more than the others with PBL, but again, no correlation with PDP is found in any analyzed case. Actually, PDP does not correlate with any group of subjects, neither with PBL nor the TFG. At this point it is also remarkable that none of the groups correlate with TFG, not even PBL and less of all of them, PDP subject. This is an unexpected result of this work, and could have an easy explanation, as the TFG is a special part of the program, with a very different score and methodological working system. TFG is performed individually and, usually, in an external company or in a research lab. It usually gets a high mark, once the objectives have been reached and the results are correctly reported. Reaching this point, the discussion should be oriented to finding a possible explanation for the obtained results. Let us move then to the why. The higher correlation of PBL with the rest of subjects would come from the methodological similarities that they share. The goals, steps and deadlines are clear and partially guided. So, as a first approach to active learning, the people with not sufficient skills regarding project development, can still find a way through the subject. On the other hand, PDP asks for the first time for very specific skills, not asked till now. And people that was forcedly embedded inside the master class methodology is for the first time able to develop other fruitful qualities. The group-working oriented project gives freedom to locate every person in the group in their most efficient position, and they greatly enjoy this new paradigm. This is something that is completely different in the TFG development. Although the student usually choses the contents of the work, that motivates and is very well fit for them, the work is mostly individual, the methodology is set by the actual supervisor and the results of the evaluation process are decided for and external committee, which evaluates the whole of the TFG.

Besides, the analysis of the linear regression between the individual basic courses' marks with the other group's individual marks, Mandatory, Elective, PBL and PDP, clearly show that there is a relevant set of students with not good performance in the basic subjects which get really high scores in PBL and even more in PDP. Something similar was observed in our previous work (Bragós, 2022), but in this later case, the primary variable was the University access mark to the engineering studies. In this previous study, however, there was also a (more reduced) set of students with high University access mark who showed low performance in project-based-subjects. In this work, we show that students obtaining low marks in basic subjects can obtain very high scores in PBL and even more in PDP subjects but brilliant students in basic analytical subjects also obtain high scores in PBL and PDP subjects, which is also an excellent result. In our opinion, the reason for the difference with the previous study is the possible higher bias in the access mark than in the internal basic courses grades as performance index. It is also clear that these performance indexes do not cover all the needed skills but only the ability to succeed in courses with analytical contents and methods.

We think that these results are very encouraging, as they confirm that PDP subjects help to exploit a wide range of skills and capabilities, and students that are not excellent in the analytical master class subjects, can brightly succeed in project-based subjects increasing their self-confidence and future self-developing. As an academic institution, and as a society, it is important to find the best way for our students to learn and reach their maximum development.

This works wants to depict the evidence that PDP subjects clearly work on the development of different skills than the ones obtained in regular, master class-oriented subjects. We would like to work more on the explanation of these results, as many questions arise from these results. Is it possible to conclude that this learning process is more important, or, better to say, complementary, to the one based only on master class development? Many well-founded research points in this direction, even concluding that this is the best procedure for the most talented students (Wieman, 2019), (Price, 2022). This is the other important question, is it the best learning procedure for all students or only for some of them, and in this case, which ones? Not all student profiles are the same, nor the capabilities or the motivations, and, although it is important that all the skills are included in the learning process, tuning which ones have to be introduced, and at which part of the process, may be of paramount importance.

We acknowledge the limitation of using only the grades as performance indexes and have asked for an internally funded project to measure the skills which are intended to be promoted in the PBL and PDP courses in a more comprehensive way. There is also a PhD thesis ongoing which will perform measurements in this direction. As a result of the feedback received from the students and of the first aforementioned study, confirmed by this one, a new elective itinerary was defined last year in two of our masters which allows the students to choose more electives around innovation and entrepreneurship instead of technological or scientific courses. These courses are mostly challenge-based. A relevant insight of the feedback was that there were students who said that they discovered their vocation about technology-based innovation in the PDP course.

CONCLUSIONS

In this work a detailed analysis comparing the student's performance in the regular, mostly analytical subjects and project-based subjects (PBL and PDP) is shown. The analysis has been made in the Telecommunications Engineering Bachelor Program, with a sample of 762 students corresponding to 4 cohorts which have followed the same curriculum. Correlation calculations have been made between the average marks obtained in basic subjects, with mainly analytical contents, and mandatory and elective subjects, also with mainly analytical contents. Other studies have been made correlating PBL and PDP performance with theoretical and practical subjects and also among the different disciplines. All studies show that whereas basic subjects highly correlate with the mandatory and elective ones (R= 0.84 and 0.69, respectively), the correlation with PBL decreases (R=0.59) and very low correlation is found between basic and PDP subjects (R=0.26). Similar results are found comparing different disciplines, where most of the disciplines correlate with the basic or science contents subjects (R ranging from 0.78 to 0.70, depending on the discipline), the correlation with the PDP subject is minimum in all of them. Regression analysis between the individual basic courses' marks with the other group's individual marks also supports that students with low marks in basic analytical courses may obtain high scores in PDP subjects, but not in the advanced analytical courses, whereas students with high marks in the analytical courses would also succeed in project-based subjects. We think that these results reassure the need of including that kind of courses as they open a way for all the students to fully develop their skills, increasing their self-confidence thus increasing their perception of a potentially good performance in their future career.

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