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Classroom Simulation of Cooperative Engineering Design Practice in an Aeronautical Company*

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A teaching experiment was conducted with students of Graphic Engineering at Madrid Polytechnic University Aeronautical Engineering School to improve their professional development in cooperative engineering design tasks in an aeronautical company. A matrix-like company structure made up of departments interacting on different projects was created. This means that the students had to collaborate and share design information. This paper describes how the experiment was organised, how it developed and the most significant results. Considerable quantitative and qualitative improvements were observed compared with the traditional methods that were used on previous courses.

Keywords: design; education; teamwork; cooperative design; aeronautical design

INTRODUCTION

NOWADAYS, apart from providing technical training as part of university studies, ever more emphasis is being placed on the acquisition of competences by students. Thus, generic competences are valued, such as teamwork, communications skills, leadership, critical thinking, etc. [1–8]. This change has been brought about by the requirements demanded by companies that take on new graduates and by the fact that various studies have clearly shown such graduates to be significantly lacking in these areas [9, 10].

In Europe, the Bologna Declaration [11] proposed a change towards the use of more active teaching methods in order to try to change the way in which knowledge and competences are transmitted, as conventional methods are not the most appropriate ones in certain circumstances and for certain purposes [3]. Thus, the teacher's role changes in the educational process and the tasks of orienting, suggesting alternative paths and promoting student progress take on greater importance [12, 13].

Promoting an active approach among students can be achieved through different methods. Among these, project-based learning is one of the alternatives that leads to good results in technological subjects [8, 13, 14].

Moreover, this project methodology usually includes a considerable group element, which strengthens some of the generic competences sought by employers [15]. However, if teamwork is defined as work being done by a group of people with a single objective who co-operate in order to achieve it and share resources [5, 16], in 15 it is shown that cases where real teamwork is developed are unusual. For this reason, some new actions are needed in order to stimulate real cooperative work.

PLANNING THE EXPERIMENT

The main objectives of Graphic Engineering, taught as part of the Aeronautical Technical Engineering degree at Madrid Polytechnic University, are as follows:

- to develop the general graphic and technological principles required for the conceptual, preliminary and detailed design of physical models and engineering systems;
- to apply quality criteria to these designs and analyse them; and
- to get to know the most common computer design applications in the sector.

Forming part of the core content are aspects of product design and specification, technological information on assemblies, (tolerances, materials etc.), machine elements (design and representation) and project documentation.

It has been observed that the knowledge and skills usually acquired by students during their studies are insufficient to tackle open-ended design tasks [17]. Traditionally, Technical Schools tend to provide analytical training for solving single-solution close-ended problems. However, design engineering involves solving problems that do not have a single solution and where the available information is insufficient. In these

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circumstances, students tend to lose sight of the important global vision of the problem and show little capacity to integrate the knowledge acquired in other subjects [18]. To undertake design tasks, the knowledge and capabilities required are identified, such as the theoretical concepts, creativity, procedures for tackling problems, practical considerations, etc. [19–21], all of which should result from university studies. Furthermore, teamwork is considered essential for design tasks, even when team members are not located at the same place [22].

In order to develop the aims of the subject better, while taking account of the above-mentioned needs, a teaching experiment was conducted where the classical teaching system was replaced by a system of a co-operative nature, involving students in tasks that come close to actual professional development in an aeronautical company. The project-based method is particularly suitable for simulating the actual development conditions of work in companies [23], although we are conscious of the clear differences (to a certain extent, insuperable) between the academic and business environment. To be precise, as can be seen in [24], in the case of teaching, the aim is to acquire knowledge and competences, while in companies, what is most important is the project itself.

In previous courses, assessment was focused on two aspects: individual student work structured around practical sessions and a final exam. Having observed certain deficiencies in this model, a change was sought, orienting the course towards simulating the reality of professional life in an aeronautical company and approaching the subject from a more active, applied and global point of view.

Preparation of the experiment was based on five basic ideas:

1. Defining the areas for action: A search for projects divided into sequences so that partial results could be obtained.
2. Defining and structuring the co-operative groups.
3. Defining the operating structure: Establishing the company's *know-how* and the basic design rules that would enable the work groups to model the preliminary design of the work.
4. Defining the criteria for dividing the work into parts of a common nature so that the different members of different groups could co-operate and create matrix-like structures to enable the different tasks to be linked.
5. Defining work methods: Defining and applying co-operative work methods deriving from their own prior results and those of other departments.

It was, thus, hoped that each group of students following the new methods would do so by developing co-operative work and always within a labour simulation framework. That is, for the group identified as an aeronautical sector company, the work to be developed would need to be able to be divided up so that all group members could take part in all the aspects of the project, either directly in running it, or indirectly as contributors.

Three design projects were chosen ('business lines') that, because of their nature, up to between 40% or 50% of which can be developed in common. The work chosen needed not only to comply with the stated condition of the common parts, but also needed to be of a sufficiently attractive aeronautical nature to motivate the student. To develop the project, the three lines of business were chosen. These business lines involve the design of three different microlight aircraft

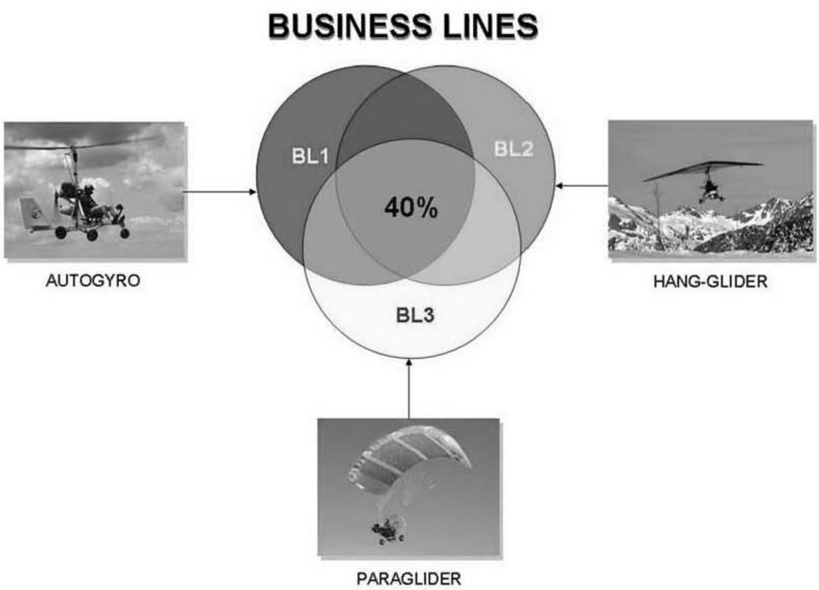

Fig. 1. Business lines planned for the co-operative work.

Table 1. Matrix-like distribution of each company (students' organization in departments and business lines).

	BL 1	BL 2	BL 3
Department 1	S1–S2	S3–S4	S5–S6
Department 2	S7–S8	S9–S10	S11–S12
Department 3	S13–S14	S15–S16	S17–S18

layouts based on a common tubular frame: a paraglider, a hang-glider and an autogyro (Fig. 1).

The common part of the three business lines was insufficient to ensure that all the members of the group ('company') could interrelate. Therefore, three departments assigned to each company, and taking a direct part in all the business lines, were set up. The tasks assigned to each department corresponded to the practical parts of each topic of the subject.

Bearing in mind the structure of the 'company', the experiment was planned with groups of 18 students, that is six students for each department and six students for each business line (Table 1 and Fig. 2). In addition, two independent companies with identical structures and the same objectives were planned. With this matrix-like structure (every department should provide compatible solutions to every project), and given the existing relationships between projects, the number of design decisions and tasks involving the student was increased. In this way, the student was not exclusively confined to a limited part of one business line, but had to contribute to the progress of all of them and offer solutions compatible with the other departments and the other business lines, with which coordination was also required. In this situation, collaboration becomes crucial and team-based activity is boosted.

For the successful progress of the experiment, it was deemed important for the students to clearly know the timeframe, so they were given a structured course guide setting out timing, project aims and work delivery schedules, as well as meetings, tutorials etc. In order that this guide will follow the business simulation chosen, it is advisable to prepare it in a similar format to the one that students will find as their professional life moves forward, such as, for example, using Gantt diagrams.

As the project was part of a subject in the final year of the degree, it seemed important to boost students' skills for presenting ideas and results. To this end, irrespective of the fact that all students at some time in their work have to give a presentation on some particular topic, two people stand out as especially significant: the head of department and the project's technical manager. In some cases, these figures will form the bridge between the teaching staff and the other students. For example, only they will be informed of some of the corrections of the interim work, and it will be up to them to make any changes known to their colleagues. It was not deemed advisable to take this procedure to the limit and was only used in cases where a mistaken transmission of knowledge would not endanger the development of the project content.

Finally, it should be pointed out that, since the experiment was highly innovative in comparison with the traditional way that subjects are taught in the School of Aeronautical Engineering, this was planned for a small number of students (2 companies of 18 students each, as previously stated). The other students registered in the subject (135 students) remained as part of the control group that would be used for comparison.

The control group and the group following the innovative experiment shared the weekly 2-hour theory classes. However, in 2-hour practical classes, the first group did and corrected individual exercises from each part of the subject in class, while the second group did co-operative work in the graphics lab, where in addition to doing the work in groups, they had the necessary computer tools at their disposal.

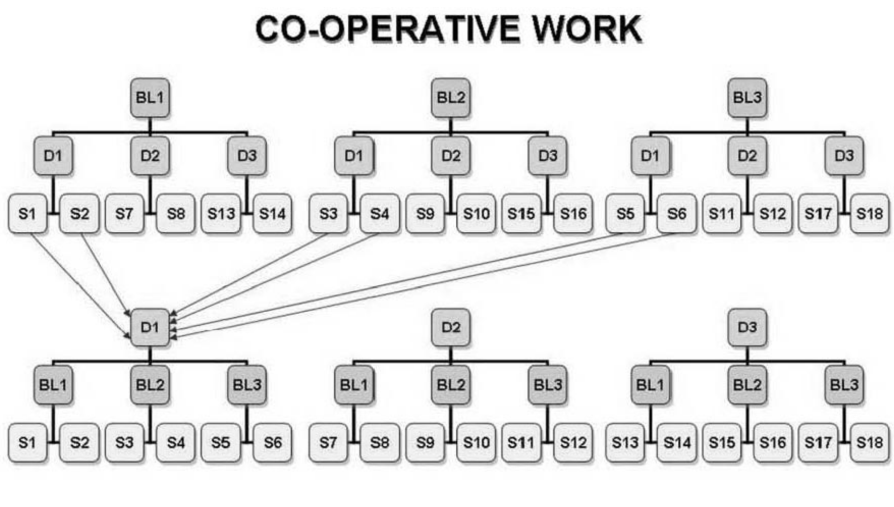

Fig. 2. Organisation of students into projects and departments.

It was hoped that this new methodology would enable students to acquire a recommended minimum level of knowledge so that in the future the final exam could be abolished by introducing changes in teaching methods. To attain this goal, the method needed to be validated, which meant that the final exam had to be taken in the same circumstances. It was also attempted to ensure that the practical sessions of the two groups as a whole were of the same order of magnitude in time and effort. Thus, the exercises on the topics for the control group and the project for the experimental group were weighted in each case as 50% of the total mark, the rest being part of the exam, for which, in addition, a minimum mark was required.

DEVELOPMENT OF THE EXPERIMENT

Day-by-day development of the experiment

The work phases were set so that the project would progress in parallel with the theory classes, which were not abolished. The experiment was monitored in the classroom and graphics lab sessions, with the main events being recorded and group actions being channelled. These practical sessions were sequentially structured so that each of the tasks would serve as a point of departure for the following task, but without being too rigid so that previous work could be reviewed. The main tasks are set out in Table 2.

The sequential process for task completion was planned following the portfolio method and methods used in sector companies, such as standard check control systems that ensure the traceability of work done, always aiming for it to be as close as possible to professional development. In this way, two goals were reached.

1. The student learns from the mistakes made by remaking the parts marked as wrong and can have their progress monitored by documenting their state of learning in the subject.
2. The student learns the importance of any changes in engineering design processes and appreciates how a good control over these changes can lead to a perfect traceability in the design. However, it should be noted that this process was by no means simple, since students tended to duplicate a lot of information and eliminate what they wrongly considered to be of no use.

The high degree of motivation among students was noteworthy, as well as their initial spontaneous organisation. Among the many spontaneous initiatives by students, we could cite the creation of a forum for exchanging ideas and monitoring the project, and the appearance of leadership among team members. However, regarding this last point, it should be indicated that a readjustment of duties had to be made so that task distribution could be systematised.

From a training point of view some initiatives were embarked upon to boost student motivation. Some of the most significant are as follows.

- To check the level of initiative and cooperation, in the first sessions, very open-ended instructions were given to one of the companies during the information search phase concerning similar elements. This situation caused some initial moments of confusion and indecision which were quickly resolved by the group members with the greatest leadership qualities who pushed the rest of the group towards more active co-operation by sharing the information found by each member. This co-operational aspect became quite naturally firmly rooted in the company and continued until the end of the experiment. On the other hand, and quite deliberately, the second company was allowed access to the information that had been compiled by

Table 2. Main design project tasks.

I. Work schedule	II. Design
1. INFORMATIVE MEETING	4. CONCEPTUAL DESIGN
Assigning timetables	Deciding general layout
Defining companies	General measures
2. ASSIGNING WORK	Standardised elements
Assigning departments	List of AMO parts
Assigning work	Conceptual Plan
Similar solutions search	Delivery of documents: AMO, Plans, . . .
In-class search	Changes and corrections
3. SPECIFICATIONS	Delivery of documentation 2nd REVIEW
Setting out specifications	5. DETAILED DESIGN
Conceptual solutions	Detailed layout
Preparing designs	Search for materials and standards
Delivery of specifications	Overall plan and parts list
Changes and corrections	Mechanical solutions
Delivery of specifications 1st REVIEW	Detailed plans
	Delivery of documentation
	Changes and corrections
III. Final delivery and presentation	

the first company. In spite of the instructions being the same, the lack of necessity and the ease of access to information led to a lower level of co-operation and an increase in individualism.

- 'Healthy competition' was promoted between the two companies by making them see that their work was, in some ways, better than the other company's. Although the information on the work progress of the two companies was public, the idea that they 'were on the right road' kept them faithful to their design criteria and steered them away from the idea of plagiarism.
- Students of both companies were allowed to enjoy free access to the CAD lab at different times from those planned for the practical sessions. This generated a permanent work space as if it were the company's design department, thereby giving a boost to group work. It also became a meeting point for developing their own initiatives (meetings, locating documentation, computer access etc.).

Another positive aspect noted was that the students became more familiar with co-operative design work and the application of design criteria that came very close to the real situation in work experience.

Some of the greatest difficulties encountered by students were as follows.

- In spite of the team's initial internal organisation, everyday work gave rise to certain functional problems within the group, particularly decision making (but not in doing the actual work). This was probably due to the fact that the students were unaccustomed to group work [15], since this is a cross-competence not promoted in other subjects.
- It turned out to be complicated for students to delimit work when this was based on an open-ended principle, a result of the closed focus approach to problems usually adopted since pre-university teaching and which continues at University [18].
- That both groups had bad management regarding the documentation generated became evident with the existence of different formats and numerous types of files, which took up more time and led to some delays.

Student workload

In this kind of experiment, estimating student work time is essential, given the definition of teaching based on ECTS credits [11, 25, 26]. Although face-to-face teaching is easily quantifiable, work outside the classroom (individual or group) is not easily estimable by the teacher, and will need adjustments throughout the length of the courses in the light of accumulated experience. In order to examine this aspect, anonymous questionnaires were gathered from students on a weekly basis, where each of the activities was listed in detail and stating whether they were individual or group activities, as well as the place where they took place.

An average dedication time of 112 hours per student was calculated throughout the 11 teaching weeks that the experiment lasted. This dedication does not include exam preparation time or the 3 teaching weeks not included in the experiment. Therefore, the total time calculated is probably somewhat more than the pre-set credits for the subject (4.6 ECTS credits, the equivalent to 115-138 hours in all). Figure 3 shows the distribution of work time. The high percentage of time in the CAD lab is particularly noticeable (many through the students' own initiative), as is the percentage of work time totally in groups (38%), which would not exist with traditional methods.

If student work time is broken down into completely subject-related tasks, with the exception of the project (I), the classroom project (II) and the project done outside the classroom (III), a

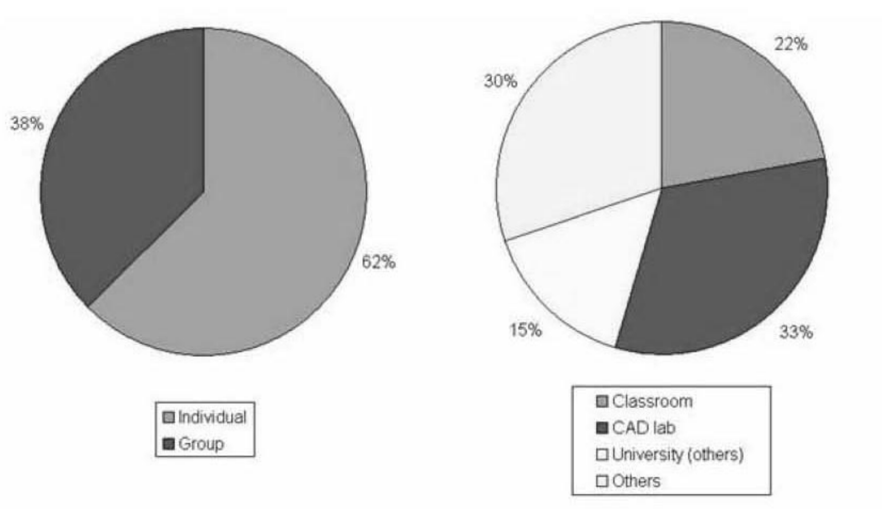

Fig. 3. Distribution of student work time.

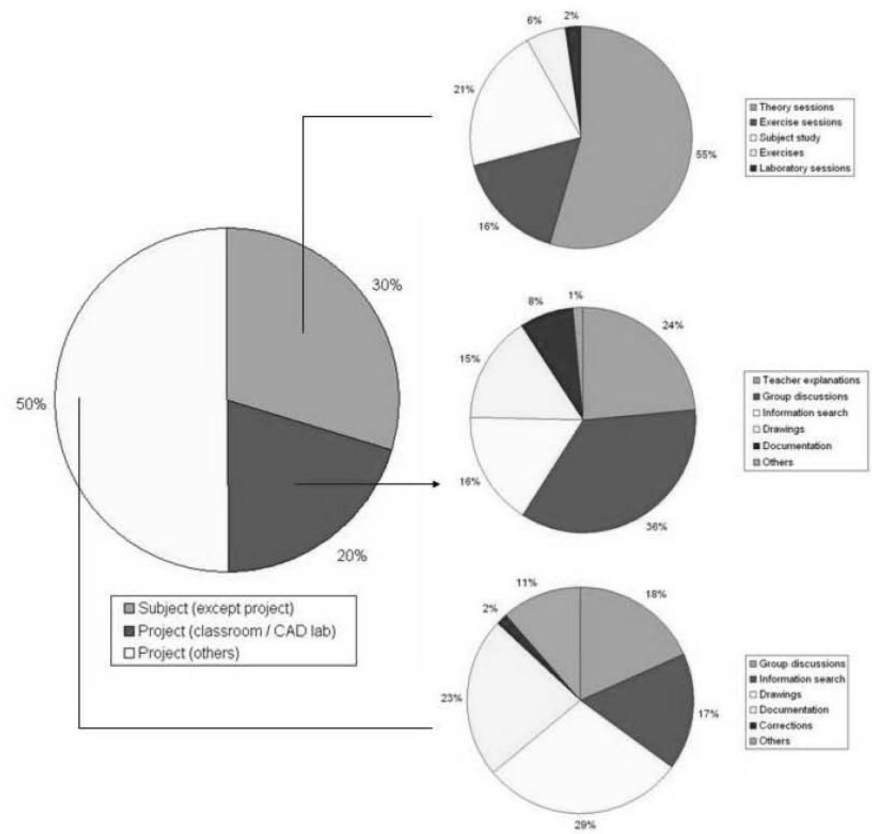

Fig. 4. Time distribution by task.

high level of dedication to the project can be seen (70%) as Fig. 4 shows. The figure also breaks down work time into concrete tasks. If the evolution of workload in each block throughout the weeks is analysed, it can be seen that the work corresponding to blocks I and II remains fairly constant, between 2 and 4 hours per week per student, however, the load corresponding to block III undergoes considerable fluctuations with a very high level of dedication (more than 15 hours per week per student, on occasions) before the interim work is submitted [27].

Student evaluation of the experiment

On completion of the project and before taking the final exam in the subject, the students filled in a questionnaire dealing with aspects of how the experiment developed.

The proposed experiment was new to students accustomed to traditional lecture methods and in-class problem solving. For this reason, an analysis of how the change in the way of working was perceived is relevant. According to the replies, on a scale of 1 (low) to 5 (high), teamwork was considered interesting and satisfactory (4.17), with close relationships between students being established (4.33) and between students and teachers (4.33). In this respect, teamwork emerged as the most positive point and the innovative experience was specifically recognised to be the key to its success. It should be indicated here that with regard to student satisfaction after working in teams, there are detailed systematic studies in the literature [16]. The system used for information feedback on the marking of work was also positively assessed (4.22).

Particularly significant is the students' perception that they did more work than their companions who followed the traditional methods (4.44), which can be identified as the main negative aspect, since they had to fit other subjects into their time. So, when answering the question, 'Do you think the project weighting in the final mark is appropriate?', 36% of students thought the project was undervalued. However, the rest thought the importance given to the project in the final mark was correct.

The global score was satisfactory (4.11). This conclusion is backed up by the fact that 77.8% of students would re-register for the experiment if they were at the beginning of the course and had the opportunity to choose.

However, in spite of the positive aspects (recognised by students) of the training acquired, it is interesting to analyse student perceptions on their preparation for the exam in the subject. In this case, 80% of students consider they are worse prepared to confront the test, in part, due to the fact that certain topics can be covered in theory classes in a more ordered and effective way. They

Table 3. Main problems encountered by students (percentage of students who marked each problem).

Bad coordination	83.3%
Planning problems	83.3%
Lack of co-operation by some group member	55.6%
Lack of job description	47.2%
Heterogeneous group	25.0%
Personal problems in the group	11.1%
Bad communication with teachers	5.6%

could also have been reinforced with specific exercises, which in the innovative experiment were only presented as part of the project. Moreover, an active or more experimental method involves a slower pace of knowledge transmission than traditional lecture procedures [28]. In spite of this, the end results, which will be shown later, do not corroborate this subjective, pessimistic appreciation that students made before taking the exam.

Finally, it was attempted to detect the main difficulties encountered so as to be able to propose corrective measures for successive reproductions of the experiment. To this end, students were asked to indicate the problems faced during project planning. Table 3 shows that questions of work coordination and planning were the most problematic. This can be explained by the fact that students were not used to working in large groups [15] with open-ended design approaches [18], as was appreciated as the experiment progressed, which led to more time being taken to do the work than initially thought necessary.

Comparison of marks

When studying the results of the exam, two main indicators were envisaged: percentage of students taking the exam and percentage that passed. To show the situation regarding the subject, we first look at the evolution of these indicators in previous courses be observed (Fig. 5). This figure shows a low number of students taking the exam (for 3 years running below 60%) and passes (below 40% in these years). In the last two courses the numbers taking the exam have been greater due to the introduction of some new teaching methods. However, in spite of the improvement, the results

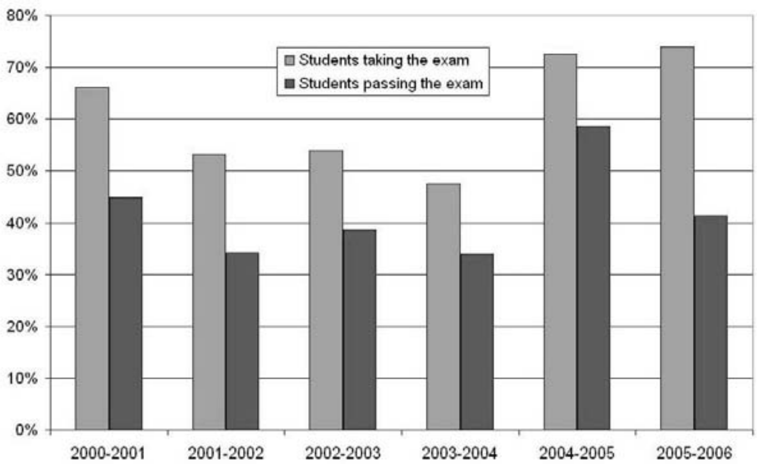

Fig. 5. Evolution of the number of students taking the exam and passes in the 2000–01 to 2005–06 courses

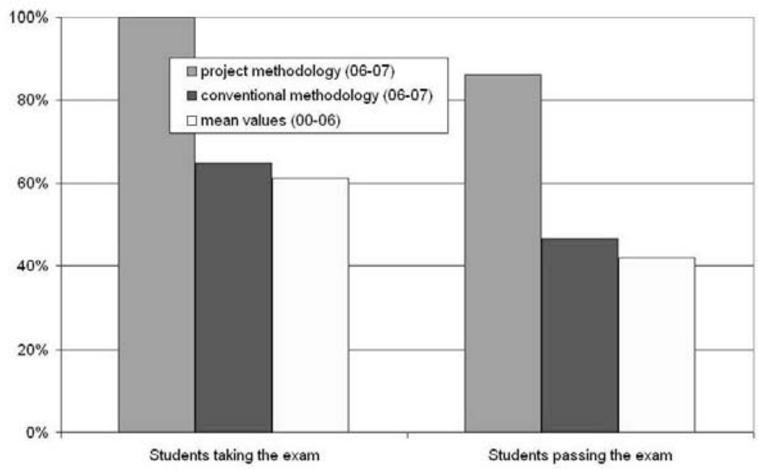

Fig. 6. Comparison of experimental group and control group data (with conventional methodology) in the 2006-07 course.

continued to be disappointing, which gave rise to the experiment presented in this paper.

For the 2006–07 course the results obtained for the exam as a whole, both for the students following the traditional methodology and those included in the project methodology, are shown in Fig. 6. From the data shown, two important things become clear.

- All the students who followed the project methodology took the exam, which indicates a greater following of the subject by students.
- The percentage of students obtaining a pass in the experimental group is considerably higher than for the group that followed the traditional methodology.

In this respect it may be said that the experiment conducted was positive, with a substantial improvement in results compared with previous years and a considerable difference between the experimental group and the control group in the two indicators used.

CONCLUSIONS

After considering the advantages that could be obtained from active project-based learning, an experiment was carried out at Madrid Polytechnic University Aeronautical Engineering School. The main innovative aspect with respect to other similar initiatives was that the experiment consisted of creating a matrix-like company structure made up of departments that interacted in different projects, which, in turn, had a large common element. The project stages were ordered so that they would progress in parallel with the theory classes, which were not completely abolished in the experiment but kept for the control group with traditional methodology.

In addition to the difficulties encountered by students in solving the technical problems that arose in the course of the project, organising them into groups is particularly critical as they are not used to this situation. The need to involve other subjects in experiments that promote these generic competences thus becomes clear, because acquiring these competences cannot be achieved with only one subject; it must be a combined effort throughout the length of the Study Plan leading to the degree.

It only remains to add that the majority of students involved in the project methodology gave a great deal of importance to issues that went beyond those directly connected with the discipline of the subject. These were issues that boosted communications skills, relationships with fellow students and teachers, leadership, commitment, responsibility, the ability to share knowledge etc. All this was shown by their unselfish cooperation in tasks to assist in the graphics lab in training first course students, and keeping up their relationship with the group of teachers. In addition, up to the present, eight of the students involved in the experiment have decided to base their end-of-course project on the ideas in the work undertaken, but they have extending it beyond mechanical design by taking account of structural and aerodynamic theory.

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