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Project Based Learning experiences in the space engineering education at Technical University of Madrid

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Abstract

This work describes the innovation activities performed in the field of space education since the academic year 2009/10 at the Technical University of Madrid (UPM), in collaboration with the Spanish User Support and Operations Center (E-USOC), the center assigned by the European Space Agency (ESA) in Spain to support the operations of scientific experiments on board the International Space Station. These activities have been integrated within the last year of the UPM Aerospace Engineering degree.

A laboratory has been created, where students have to validate and integrate the subsystems of a microsatellite using demonstrator satellites. In parallel, the students participate in a Project Based Learning (PBL) training process in which they work in groups to develop the conceptual design of a space mission. One student in each group takes the role of project manager, another one is responsible for the mission design and the rest are each responsible for the design of one of the satellite subsystems. A ground station has also been set up with the help of students developing their final thesis, which will allow future students to perform training sessions and learn how to communicate with satellites, how to receive telemetry and how to process the data.

Several surveys have been conducted along two academic years to evaluate the impact of these techniques in engineering learning. The surveys evaluate the acquisition of specific and generic competences, as well as the students' degree of satisfaction with respect to the use of these learning methodologies.

The results of the surveys and the perception of the lecturers show that PBL encourages students' motivation and improves their results. They not only acquire better technical training, but also improve their transversal skills. It is also pointed out that this methodology requires more dedication from lecturers than traditional methods.

Keywords: Active learning, Project Based Learning, Team work, Satellite design.

Acronyms list

AFSK: Audio Frequency Shift Keying
APSK: Amplitude Phase Shift Keying
BPSK: Binary Phase Shift Keying
CDIO: Conceive - Design - Implement - Operate
CG: Control Group
E-USOC: Spanish User Support and Operations Center

ECTS: European Credit Transfer and Accumulation System
EHEA: European Higher Education Area
ESA: European Space Agency
ESA CDF: ESA Concurrent Design Facility
ESW: Experimental Software
GENSO: Global Educational Network for Satellite Operations
GFSK: Gaussian Frequency Shift Keying
ISS: International Space Station
MCS: Mission Control System
Morse CW: Morse Code, Morse Continuous Wave
MWIRD: Medium Wave Infrared Detector
NIT: Near Infrared Technologies
NOAA: National Oceanic and Atmospheric Administration
PBL: Project Based Learning
PCM: Phase Changing Material
STK: Satellite Tool Kit
UPM: Universidad Politécnica de Madrid (Technical University of Madrid)
VEII: Space Vehicles II

1 Introduction

In recent years, a transformation in teaching and learning methods in European universities has taken place, aiming at increasing active learning (Johnson et al. 1998, Prince, 2004). The transformation has been mainly driven by the creation of the new European Higher Education Area (EHEA) (Ministers of Education of the European Union 1999). The model proposed by EHEA involves the transition from an education system based on teaching to a system based on learning, making the student the center of the educational process.

The application of these new models particularly benefits engineering education, because training in engineering has an essential practice component. In particular, subjects in the second cycle of the degree, which have a very technological and systematic nature, are more suited to implement active learning methods such as Project Based Learning (PBL) (Kjersdam and Enemark, 1994, Luxhol and Hansen, 1996, Krajcik et al., 1999, Thomas, 2000, Frank and Elata, 2003, Mills and Treagust, 2003, Dym et al., 2005). PBL enhances not only the students' acquisition of competences specific of each subject, but also the development of generic competences as communication, team work, leadership, etc., that are increasingly valued in the professional field.

This work describes the educational innovation activities performed in space engineering education since the academic year 2009/10 at the UPM, aligned with the model proposed by EHEA. These activities have been performed in collaboration with the Spanish User Support and Operations Center (E-USOC, www.eusoc.upm.es), a center in the UPM delegated by the European Space Agency (ESA) to operate scientific experiments on board the International Space Station (ISS); it supports fluid science experiments performed within the European Columbus Laboratory and experiments in the Microgravity Science Glovebox in the U.S. Destiny module of the ISS.

These innovation activities have been integrated along the last semester of the Aerospace Engineering degree at the Higher Technical School of Aerospace Engineering of UPM. Students in this semester have not been exposed to Project Based

Learning previously, and after completing their five-year degree they usually transition directly into industry.

The main activities implemented are: a) “Use of demonstrator satellites for teaching” and b) “Conceptual design of a satellite mission”, which have been both integrated in the “Space Vehicles II” (VEII) course; c) “Development of a satellite tracking ground station”, d) “Development of a laboratory satellite”, and e) “QB50 project”, which have been integrated as Final Thesis.

The “Conceptual design of a satellite system” was introduced in VEII in the academic year 2009/10. In order to improve its outcomes, in the following three years it was reshaped taking into account the lecturers and students feedback. The “Use of demonstrator satellites for teaching” was introduced in the academic year 2010/11, and was also modified in the next academic year. In the years 2012/13 and 2013/14, the VEII course structure was frozen and several surveys were conducted. The main objective of these surveys was to evaluate the impact of the PBL methodology in the students’ engineering skills, in their acquisition of generic competences, and to determine the students’ degree of satisfaction. The principal results are summarized in this paper.

The work is organized as follows: section 2 describes the main learning activities performed. A description of the application of PBL methodology is contained in section 3, and its main results are presented and discussed in section 4. Sections 5 and 6 summarize the instructors’ perception and the overall conclusions, respectively.

2 Activities description

The main goal of the activities carried out has been giving the students a training as complete as possible, covering both the engineering learning and the acquisition of generic skills and maturity. Moreover, all the activities were aimed at bringing the students closer to the current technologies and to the way of working in the aerospace industry.

The design of the activities was done not knowing the CDIO initiative, led by a team at the Massachusetts Institute of Technology (MIT) (Crawley 2002, 2011) and implemented by over 20 Universities worldwide (Smith, 2011). Even though the CDIO syllabus was not known to the authors, the underlying design principle of the activities implemented is fully in line with this international effort. The CDIO design principle is basically that “the graduating engineers should be able to conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment” (Crawley, 2007). And in order to do it effectively in an enterprise, societal and environmental context, they should also possess qualities such as teamwork, leadership, and communication.

In this context, the activities at UPM were designed to give the students the opportunity to cover the complete space vehicle life cycle. As the duration of the VEII course was not enough (6 hours of formal class per week, for 10 weeks), it was decided to introduce the design, integration and verification phases in the VEII course, and leave the implementation and operations phases for the Final Thesis.

The learning objectives of VEII are:

- To comprehend the relations between the space vehicle subsystems
- To comprehend the implications of different requirements
- To be able to design a space vehicle (mission and subsystems) given the mission statement. Identifying different design possibilities, being creative, managing imprecise and scarce data

- To comprehend the integration and validation phases in a space vehicle project
- To be able to write good quality technical reports
- To be able to effectively present and defend the work performed
- To be able to use technical documentation and specifications
- To be able to manage the work time
- To be able to collaborate with other engineers effectively

The Final Thesis is an individual work led by a lecturer, the subject matters being diverse. The amount of students who were able to follow the Final Theses described below were few due to the limited number of places available.

Next, the different activities performed are described.

2.1 Use of demonstrator satellites for teaching

During the 2010/11 academic year a new laboratory was created, where students work in groups to carry out the integration and validation of the subsystems of a microsatellite. To set up the laboratory some equipment (e.g. PCs, power supplies, multimeters) and an educational microsatellite were acquired. The educational microsatellite serves to demonstrate the basic functionalities of a satellite, and due to the high demand from students and the success of the practical lessons a second unit was acquired during the 2011/12 year.

The subsystems which the students have to integrate and validate are: power, data handling, communications, attitude control and thermal control. Some of the activities performed by the students are the verification of:

- The solar panels, obtaining their P-I and V-I profiles
- The peak power tracker performance in different illumination conditions
- The electrical voltages and currents for different load profiles
- The power switches funtionality
- The mass properties of all subsystems and of the integrated satellite
- The telemetry measurements calibration
- The telemetry data rates, and verification of the telecommands
- The attitude determination and control sensors and actuators
- The attitude control algorithms

A set of manuals and procedures were developed, making an effort in presenting and conducting these practices in a way as close as possible to real satellite verification tests: the satellite and each of its subsystems are first presented so that students are familiar with their design, features and specifications; after that, procedural steps have to be followed carefully, assessing the results against the applicable specifications; finally the students prepare the test reports and fill a requirements validation matrix. Each subsystem is verified individually before assembling it with the previously verified modules and performing an integrated verification. Once all modules have been tested and assembled, the complete satellite is tested in its final configuration.

The groups have to work as a team and organize each of their members' tasks in order to ensure an efficient use of time and resources, and the proper level of safety; the latter is supported by a lecturer monitoring their work.

Students are able to get in close contact with practical aspects of satellite design, development and operation:

(i) They are able to see, use and perform a series of tests and measurements on a functioning satellite and its components. This allows them to get familiar with satellite components and their performances, as well as with laboratory test equipment and procedures.

(ii) They are able to communicate with the satellite and gain experience with some of the capabilities and limitations related to remote operation and monitoring.

(iii)They get a first hands-on contact with integration and verification activities as they are performed in space industry (within the limitations imposed by the demonstrator satellite itself, by the laboratory environment and by organizational aspects such as duration of the lessons and number of students); these activities have a big impact in the overall cost of a satellite project and are usually not well understood when studied only from a theoretical perspective.

With this activity several topics in the CDIO syllabus have been implemented, among them are: Team Operation; Communication Strategy and Structure; Written Communication; System Engineering, Modeling and Interfaces; Hardware Software Integration; Test, Verification, Validation, and Certification (Crawley 2011).

2.2 Conceptual design of a satellite mission

Students work in groups to develop the conceptual design of a satellite mission. Each group member adopts a specific role and they have to work and communicate as an engineering team to define their mission requirements, derive the system and subsystem requirements, design the different subsystems in accordance with those requirements and ensure the consistency and feasibility of the overall design.

The mission statement of each project is defined by the respective team. Some examples of the projects developed are:

(i) Provide images of high latitude oceans of interest for sea transport. The images should allow the analysis of the ice caps melting to assess the feasibility and safety of maritime routes in high latitudes.

(ii) Achieve a microgravity platform to perform material science experiments in microgravity.

(iii) Obtain a map of the celestial sphere in the near ultraviolet and far ultraviolet frequencies.

(iv) Achieve a global monitoring system for the low frequency variations of the Earth magnetic field preceding the earthquakes, in order to provide earthquakes early warning.

(v) Provide full coverage to the Juan Carlos I Antarctic Base so that the analysis of the information it gathers can be efficiently processed and analyzed in near real time.

(vi) Detect, register and follow up the forest fires in the Iberian Peninsula, and transmit the information to the firefighting systems.

The change of the teaching and learning model has required obtaining educational licenses of the following software tools, widely used in the space industry:

(i) The mission analysis software STK (Satellite Tool Kit).

(ii) The satellite thermal control system design software ESARAD-ESATAN.

The details on how this activity was implemented are described in chapter 3.

2.3 Development of a satellite tracking ground station

The best European universities in the aerospace field carry out design and implementation of real projects, by which students acquire a sound training in both contents and generic competences. In some cases, these projects result in satellites orbiting the Earth and sending telemetry accessible to any ground station that meets the required specifications, such as the Delfi-C3 (http://www.delfispace.nl/). In addition to this type of satellites, important observation satellites such as NOAA (National Oceanic and Atmospheric Administration, http://www.goes.noaa.gov/) also offer open telemetry. There is also an ESA initiative for the creation of a worldwide ground network to receive data from on-orbit university satellites under the tutelage of ESA, called GENSO (Global Educational Network for Satellite Operations, http://www.genso.org/).

And in 2012 the QB50 project (https://www.qb50.eu) was started, a project funded by the 7th Framework Program to launch and operate an international network of 50 CubeSats, which is described in section 2.5.

All these potential uses led to the construction of a ground station (see Figure 1) to allow the communication with open satellites, downlinking their data and processing it on ground. The station has been installed at the E-USOC.

Figure 1. Satellite tracking ground station antenna

The set-up of the station and its Monitoring and Control System was carried out through several Final Theses. The results of these works were validated by acquiring and interpreting telemetry from several operational university satellites.

Thanks to the set-up of the ground station, students can now perform training activities which allow them to learn:

(i) How to communicate with satellites
(ii) How to download telemetry and how to process the data

Students have downlinked data from several satellites and provided them to their respective teams, who have a system set-up to collect it. The satellites tracked so far are Compass One (beacon and housekeeping in Morse CW), Hope One (beacon and housekeeping in Morse CW), O/Oreos (data uploaded to the mission web page: beacon and housekeeping in AFSK 1200 bps), Swiss Cube (science data automatically forwarded to the SwissCube MCS: BPSK AX.25, 1200 bps), Eyesat AO-27 (APSK AX.25, 1200 bps), PolyItan (GFSK AX.25, 9600 bps), QB50 precursor flights (data uploaded to the mission web page: housekeeping BPSK AX.25 1200 bps and CW beacon).

Working with real satellites allows addressing the work in a more realistic way, which is very motivating for the students.

2.4 Development of a laboratory satellite

The demonstrator satellites acquired in previous years are good for conducting laboratory practices in the subject, but do not provide adequate flexibility for students to engage in new hardware and software developments. Therefore, the development of a self-designed demonstrator satellite was started through Final Theses.

Five students have been involved in this activity carrying out their theses: two in the Electric Power System design, two in the Attitude Control System design, and one in the Mechanical design and overall integration.

The development is currently in its final stage and it is foreseen that it will be ready for the first semester of 2015/16. Having an in house development will also allow to have more units and to significantly reduce costs.

2.5 QB50 project

QB50 is a project funded by the 7th Framework Program to launch and operate an international network of 50 CubeSats. Their mission is dedicated to the acquisition of multi-point in-situ measurements of key components of the thermosphere and lower ionosphere, and to the research of the re-entry into the atmosphere. It will be the first big network of CubeSats on orbit, a concept that has attracted much interest in recent years, but so far no university, institution or space agency had taken the initiative to create and coordinate.

A team of UPM professors submitted a proposal to the QB50 project, which was selected and has been carried out during the 2012-15 timeframe. The overall objectives of the proposal are the design, development, construction, launch and operation of one of the two-unit CubeSats of the network, which will carry an atmospheric sensors kit provided by the consortium. A secondary objective of the mission is the in-orbit demonstration of a new attitude control system (Experimental Software, ESW) developed by the UPM team, and two other payloads developed in collaboration with the University of Liege and with Near Infrared Technologies (NIT), respectively: a phase changing material (PCM) and a medium wave infrared detector (MWIRD).

The project has a high educational, scientific and technological value for universities. It will allow UPM to be part of an international group of more than 90 universities worldwide working and sharing knowledge for a successful mission. In addition to the universities developing and operating the satellites, other universities are participating in the creation of a ground stations network to support the operations of the satellite constellation and maximize the amount of scientific data downlinked.

The 7th Framework Programme funds 75% of the launch cost, as well as the development and manufacture of the scientific sensors and the procurement of a few Attitude Determination and Control Units. The remaining 25% of the launch cost, and the design, manufacture and operation cost of the CubeSats and ground stations of the network must be funded by the project participants.

The UPM satellite is called QBito. The project is being designed and manufactured by final-year students of the degree, led by lecturers and E-USOC staff. It has been very challenging to be able to develop such a project with a high participation of students, since attending other courses was not always compatible with the project schedule and its fixed milestones. Only their very high motivation and commitment with the project made it possible. The full design of several subsystems was done with the involvement of students, namely: the electric power system (three students), the structure (two students), the thermal control system (two students), the ESW (two students), the communications system (one student), the harnesses (one student), the ground software (two students) and the on-board software (two students). All these students have been working in the project as their Final Thesis. Some students were able to participate in the initial phase of the project, more focused on the design; others in the procurement, manufacturing and validation phase, having direct interaction with the industries where the tests are being performed (i.e. SENER and AIRBUS DS); and others have been able to participate in all the phases.

The participation in international projects allows the internationalization of teaching, promotes students' interest and increases their motivation.

3 PBL methodology

PBL is a learning model that organizes learning around projects. Thomas (2000) lists five aspects that have to be considered in PBL projects:

- Projects are central, not peripheral to the curriculum,
- Projects are focused on questions or problems that drive students to encounter the central concepts and principles of a discipline,
- Projects involve students in a constructive investigation,
- Projects are student driven to some significant degree,
- Projects are realistic, not school like.

Moreover, PBL methodology emphasizes activities which:

- are long-term,
- are student-centered,
- are based on collaborative team learning,
- are integrated with real world practices,
- have productive outcomes,
- have an impact on skills like self-management, teamwork, leadership, time management, communication and problem-solving,
- use technology-based tools

Several authors have pointed out the benefits of this kind of methodologies. In particular, PBL increases motivation and satisfaction of students (Green, 1998, Orevi and Danon, 1999, Thomas, 2000, Frank and Elata, 2003, Kamp, 2012) and develops skills increasingly in demand in the business world, that classical methods do not develop (Saunders-Smits and de Graaff, 2003). Krajcik et al. (1999) point out the benefits of collaboration among students as they have to learn to work together to find solutions to problems, and how the PBL methodology promotes responsibility and independent learning. Orevi and Danon (1999) note also other advantages of PBL, as it develops data collection and presentation skills, thinking skills, suits personal learning styles and develops independent learners. In the PBL environment, students build their own knowledge by active learning, interacting with the environment, working independently or collaborating in teams, while the teacher directs and guides (Thomas, 2000).

3.1 Implementation of PBL methodology in VEII

At the beginning of the semester, the students have to choose between two options to follow the 6 ECTS (European Credit Transfer and Accumulation System) course (VEII):

- To attend the classes but not to participate in the PBL. These students are evaluated by using a final exam at the end of the course
- To participate in the PBL

All the students participate in classes focused on the more practical aspects of the spacecraft design. In these classes they can work in groups with the support of a lecturer who helps and guides them.

Students participating in the PBL methodology are organized in groups of 6 to 7 members to develop the conceptual design of a space mission. Each student takes one of the following roles within the group:

(i) Project manager,
(ii) Mission analysis engineer,
(iii) Mechanical engineer,
(iv) Electrical engineer,
(v) Propulsion engineer,
(vi) Orbit and attitude control engineer,
(vii) Payloads engineer.

Each role is responsible for the design of the corresponding subsystem. This requires that all students study their subsystem and how to integrate it into the whole system; it is therefore necessary for them to negotiate with the other team members, since decisions on each subsystem affect the requirements and design of other subsystems, hence affecting the design and final performances of the system. Transmitting the relations among subsystems is always a hard task in theoretical classes, but is very well understood by students with this exercise.

With this learning methodology the students do a similar work to that developed in different companies and space agencies in the preliminary stages of a project such as, for example, the ESA Concurrent Design Facilities (CDF), where experts in each of the areas come together for a limited time, usually less than a week, to develop a feasibility phase of a space mission. Such offices exist also in the CNES, Airbus Defense and Space, etc.

Evaluation of student performance is one of the most difficult tasks in PBL courses (Dutson et al., 1997). When it involves team work it is often difficult to identify the effort and results of each student. In these courses the work evaluation is done through the following tools:

- Monitoring of groups in the classroom: at least 1.5 hours/week of team work are conducted in the classroom with a lecturer who monitors and guides students in their work.
- Regular presentations along the semester where each group presents its Mission Analysis and Subsystems design. Each presentation is evaluated and, if significant errors are detected, they must be corrected for the final presentation.
- Several deliverables are handed along the project timeframe: the mission requirements document is delivered in the first week, the mission analysis report is delivered in the fifth week, and the mission final report is delivered in the tenth week. The two first reports are evaluated, and if significant errors are detected they must be corrected before the final report is delivered.
- Oral evaluation at the end of the course where:
    - Each group prepares a presentation.
    - Two students of the group are selected at the moment of the oral presentation to give it.
    - After the presentation, there is a round of questions where all students in the group have to defend their design. Each student

has to answer several questions on the subsystems he has not been responsible for.

- A self-evaluation and peer evaluation is performed. Each student rates his work and the work of each and all the members of his group.

The project is performed in 54 hours of classwork (including theoretical classes focused on the project, the oral presentations and the team work classes), during 10 weeks.

The individual mark for each student is obtained from the final report (50%); the final oral presentation (40%); and the self-evaluation and peer evaluation (10%). It should be highlighted that the peer evaluation happened to be very much in line with the appreciation that the lecturers had on the individual work performed by the students, but it was important to reassure it.

Five projects were presented in the academic year 2010/11, nine in 2011/12, eight in 2012/13 and seven in 2013/14.

4 Results

Pre and Post-Surveys have been conducted along the academic years 2012/13 and 2013/14 (at the beginning and at the end of the course) to evaluate the effect of PBL, not only in the technical knowledge of the students, but also in transversal or generic competences. The surveys were anonymous and telematic; the students were granted access to the survey through the UPM intranet. The first survey was distributed at the very beginning of the course, and the last one once the course was over and before the grades were published. An identification number was assigned to each student who answered. Table 1 summarizes the amount of students enrolled and how many answered to the surveys performed. A total of 124 students responded to the pre-questionnaire (93 male and 31 female) out of 171 enrolled students. There were 122 valid responses to the post-questionnaire (92 male and 30 female). A total of 90 students answered both questionnaires (33 in the 2012/2013 academic year and 57 in the 2013/2014 one). As there weren't any questions about the learning methodology in the pre-survey, for the statistics purposes, the two groups of students have only been differentiated in the post-survey:

- Students involved in the PBL (PBL students, 83 in total).
- Students who have attended the classes but have not been involved in the PBL process (Control Group, CG, 39 in total).

The pre-survey has been used as a whole survey and only to check the self-assessment of the students at the beginning of the course, but not to compare with the results at the end of the course because the respondents don't match.

Regarding the type of questions, they can be grouped in four different blocks:

1. Technical questions about the subject
2. Questions about the self-assessment of learning
3. Questions about the subject in general
4. Questions about the PBL model

The first and last blocks were only responded at the end of the course, and the last block was only responded by students who had followed the PBL methodology. The two other blocks of questions were responded by all the students at the beginning and at the end of the course. All the questions of the surveys are Likert scale questions in a 1 to 5 scale being: 1 (Strongly disagree), 2 (Disagree), 3 (Undecided), 4 (Agree), 5 (Strongly agree).

	Course 12-13	Course 13-14
# Total of enrolled students	60	111
# Total of PBL students	47	70
# Students responding pre-questionnaire	47	77
# PBL students responding post-questionnaire	36	47
# CG students responding post-questionnaire	7	32

Table 1. Amount of students enrolled and amount of valid respondents to the surveys

4.1 Technical questions about the subject

This section contains the results of the surveys performed to analyse the self-perception that both groups of students (PBL and CG) have about their knowledge of the technical aspects of the subject. The overall results are presented in Table 2. This table shows the questions in the survey and the mean of the answers to each question for both groups of students, along with its standard error. These results are also depicted in Figure 2. As it can be seen in this figure all the scores of the PBL students are higher than those of CG students. For each question a contrast to test if there are statistically significant differences in the mean response has been performed, finding that for all the questions, but 3rd and 4th, the *p*-value is less than 0.05, so the difference between the PBL and the CG students mean responses can be considered statistically significant. The non-significant difference in the mean response to questions 3 and 4 can be explained because none of the groups implemented the referred stabilization systems in their vehicles. According to these results, it can be stated that PBL students feel more confident about their technical knowledge of the subject than CG students. Similar results about the gain in the subject areas with the use of PBL methodology have been also pointed out by other authors (Thomas, 2000).

Figure 3 shows the histograms with the distribution of the answers to some questions shown in Table 2. It is interesting to note that the main differences in the answers are in the most extreme values (scores 1, 2 and 5). It is remarkable that a great majority of the PBL students think they have at least a medium knowledge of the technical aspects targeted in the questions.

Questions	Mean Control Group	Mean PBL students	Statistically significant difference
1. Apply the thermal balance of a satellite to calculate the temperatures	3.08±0.16	3.45±0.10	Yes
2. Determine the necessary sensors for satellite attitude	3.28±0.15	3.84±0.09	Yes
3. Understand the passive stabilization system by spin and apply it to a particular satellite	3.23±0.0.14	3.34±0.10	No
4. Understand the passive stabilization system by gravity gradient and apply it to a particular satellite	3.08±0.0.16	3.25±0.11	No
5. Understand and size the needs of management and archiving data in a space mission	3.15±0.14	3.50±0.10	Yes
6. Size the communication system of a spacecraft	2.87±0.13	3.38±0.11	Yes
7. Understand the interrelationships between the different subsystems of a spacecraft	3.53±0.17	4.25±0.09	Yes
8. Understand how the integration of the subsystems of a spacecraft must be done	3.32±0.18	3.90±0.10	Yes
9. Understand how the EPS works	3.155±0.18	3.80±0.12	Yes
10. Understand how the DHS works	3.08±0.18	3.49±0.10	Yes
11.Understand how the ACS with reaction wheel works	3.21±0.19	3.92±0.10	Yes
12. Perform an analysis of a space mission	3.47±0.17	4.05±0.09	Yes

Table 2. Technical questions about the subject. From 1(Strongly disagree) to 5 (Strongly agree)

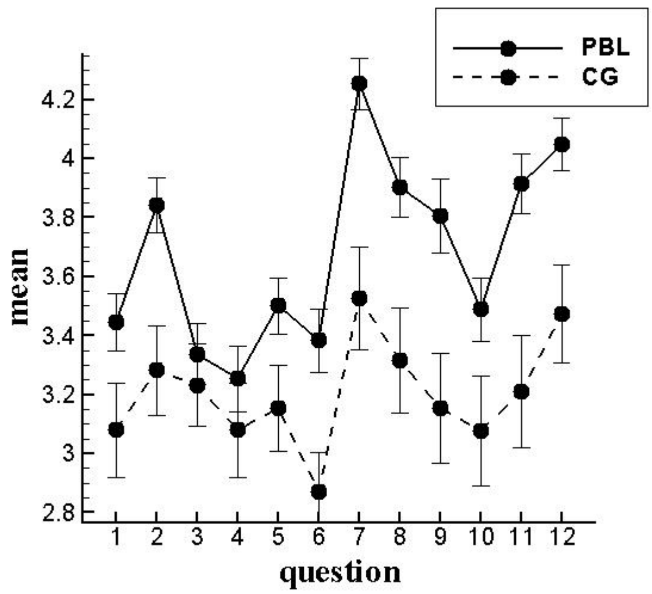

Figure 2.. Results from survey about technical questions (see Table 2)

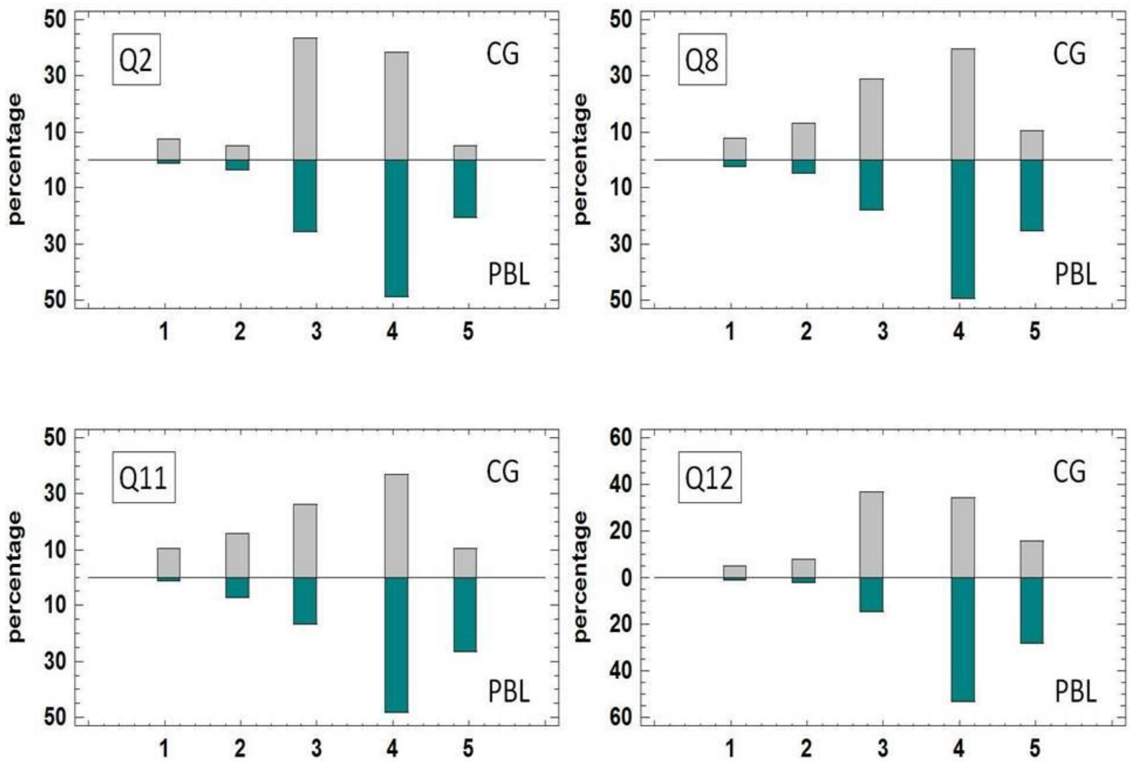

Figure 3. Histograms of answers to questions 2, 8, 11 and 12 of Table 2. Upper bars correspond to the CG students and lower bars to the PBL students

4.2 Questions about the self-assessment of learning

This section contains the results of the survey performed to analyse the self-assessment that both groups of students (PBL and CG) have about some generic competences that the PBL methodology should enhance. Table 3 shows the questions in the survey and the mean of the responses to each question at the beginning of the course

(Pre) and at the end of the course (Post) for both groups of students. Again, a contrast of mean difference has been performed between the answers of the CG and PBL students of the post-survey, resulting that there is a statistically significant difference (with *p*-value less than 0.05) for the questions 4 (oral communication), 6 (team work), 7 (time management) and 9 (creativity). These results are also depicted in Figure 4.

It is interesting to see that for some questions, such as the second (*Solving problems*) or the third (*Synthesis*), both groups of students (PBL and CG) had a higher self-evaluation score before taking the course than after the end of it. Anyhow, in all the cases the PBL students have a better self-evaluation score about all the competences targeted than the CG students. The higher self-evaluation score before taking the course could be explained because their previous learning experiences have been based on systematic questioning, as it is explained in section 5.

In other experiences with PBL in Aerospace engineering degrees (Saunders-Smiths and de Graaff, 2003) students of the last years (2nd and 3rd) were also asked to perform a self-assessment on their teamwork, solving problems and synthesis skills before and after the PBL. In that case there was no comparison with a control group because all the students participated in the PBL. In general, the surveys showed an improvement of students' synthesis, solving problems and team working skills. But in that case the students had participated in a PBL course in the first year of the degree, and they could have a more realistic self-assessment about their solving problems or synthesis skills at the beginning of the course. Figure 5 shows the histograms with the distribution of the answers to questions 1 and 7 of Table 3.

Questions	Mean (Pre)	Mean (Post) Control Group	Mean (Post) PBL students	Statistically significant difference between CG and PBL
1. Relationship between theory and practice	3.63±0.07	3.59±0,11	3.79±0.08	No
2. Solving problems	3.66±0.07	3.29±0.15	3.47±0.09	No
3. Synthesis	3.83±0.08	3.58±0.13	3.73±0.09	No
4. Oral communication	2.94±0.09	2,95±0.19	3.57±0.11	Yes
5. Writing	3.73±0.09	3.70±0.17	3.74±0.09	No
6. Team work	3.80±0.08	3.83±0.17	4.21±0.08	Yes
7. Time Management	3.41±0.09	3,22±0.19	3.73±0.09	Yes
8. Leadership	3.58±0.08	3.46±0.16	3.70±0.08	No
9. Creativity	3.46±0.09	346±0.0,14	3.76±0.09	Yes

Table 3. Questions about the self-evaluation on generic competences. From 1(Strongly disagree) to 5 (Strongly agree)

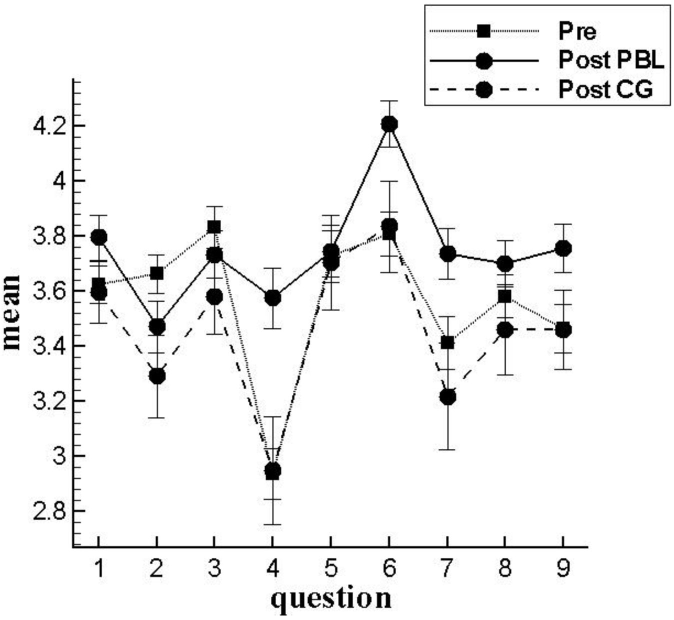

Figure 4. Results from the surveys about the self-assessment on generic competences (see Table 3)

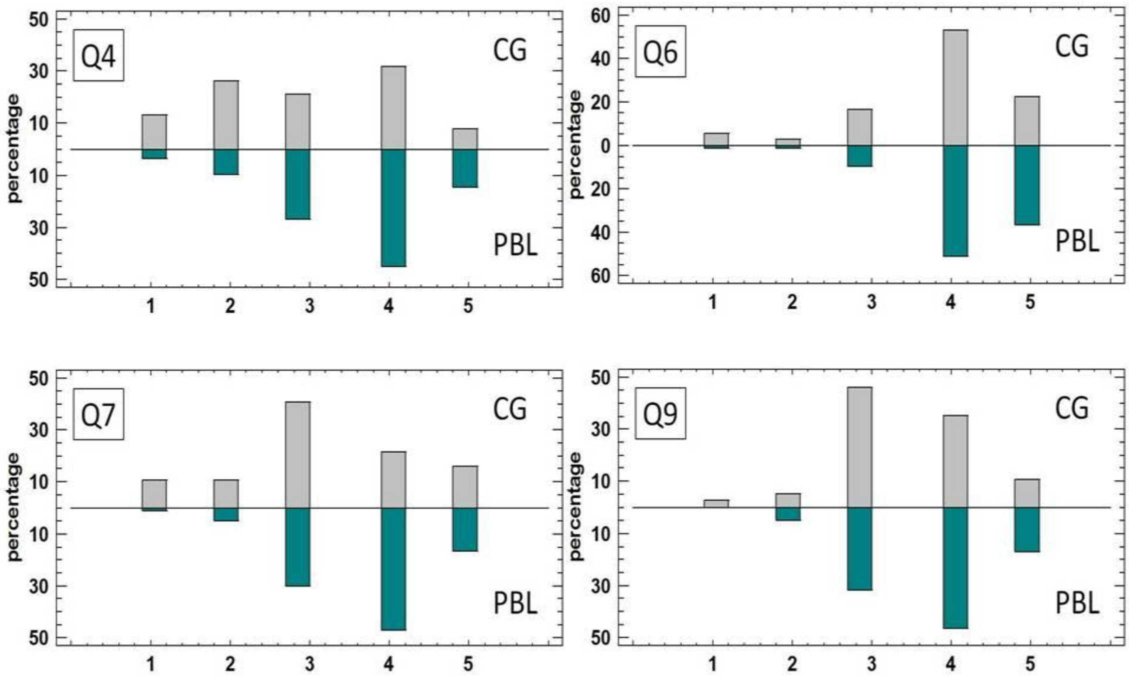

Figure 5. Histograms of answers to questions 1 and 7 of Table 3. Upper bars correspond to the CG students and lower bars to the PBL students.

4.3 Questions about the subject in general

This section contains the results of the survey performed to analyse the general perception that both groups of students (PBL and CG) have about the subject. Table 4 shows the questions of the survey and the mean of each response at the beginning of the course (Pre) and at the end of the course (Post) for both groups of students. As it can be seen in the scores, PBL students show a higher interest in the subject than CG students. Other studies based on self-report data have noted that most of the students involved in

PBL agree that projects help motivate them and indicate increased interest in the topics involved (Thomas, 2000).

Questions	Mean (Pre)	Mean (Post) Control Group	Mean (Post) PBL students	Statistically significant difference between CG and PBL
1. Your interest in the subject	4.37±0.07	4.00±0.12	4.39±0.08	Yes
2. The relevance you think the subject will have in your training as an engineer	4.08±0.08	3.90±0.15	4.31±0.07	Yes
3. Level of difficulty of the subject that you expect (Pre) Level of difficulty of the subject (Post)	3.97±0.07	4.23±0.10	4.20±0.07	No

Table 4. General questions about the subject. From 1(Strongly disagree) to 5 (Strongly agree)

4.4 Questions about the PBL methodology

This section contains the results of the survey performed to analyse the perception that PBL students have about the PBL methodology. Table 5 shows the questions on the survey and the mean of the responses to each question. These results are also depicted in Figure 6. Figure 7 shows the histograms with the distribution of the answers to questions 1 and 4 of Table 3.

The results show that students consider that the PBL methodology requires more work from them, as has also been pointed out by other authors (Manson, 2004). As it is explained in section 5 the students have difficulties facing the project because their previous learning experiences have been based on the deterministic, engineering science approach (Dym et al. 2005). The change is difficult for them because they have to develop new skills and to adapt their learning styles. Moreover, students sometimes invest too much effort in the project and perform much more work than needed to fulfil the project objectives. This is an issue that the instructors have tried to correct by several means, such as limiting the amount of pages in the reports.

However, although the students feel they have to work harder they would recommend it to other students because they understand that they learn more than with the traditional methodologies, and develop generic competences which are not acquired with the traditional methodologies.

Questions	Mean PBL students
1. Do you think that with this learning methodology you learn more?	4.39±0.09
2. Does this methodology make you work harder?	4.58±0.08

3. Do you think with this methodology you develop skills that you don't acquire with the classic one?	4.37±0.09
4. Are you satisfied with the results considering the work done?	3.43±0.13
5. Will you recommend to choose the PBL option to other students?	3.88±0.13

Table 5. Questions about the PBL methodology. From 1(Strongly disagree) to 5 (Strongly agree)

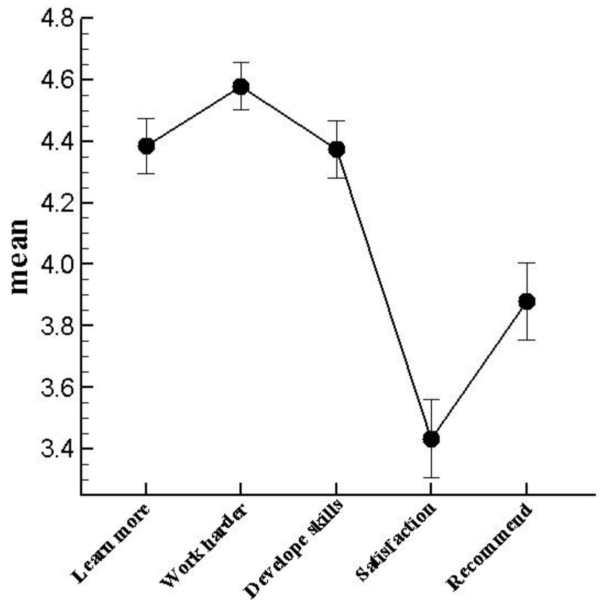

Figure 6. Results from survey on the PBL methodology (see Table 5)

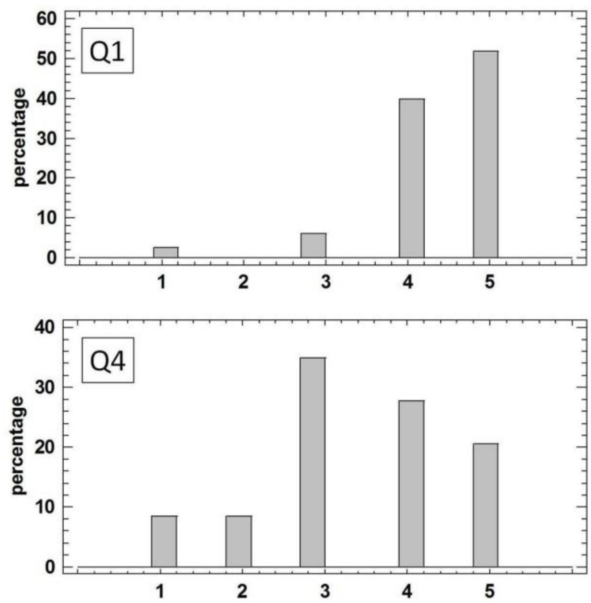

Figure 7. Histograms of answers to questions 1 and 4 of Table 5

4.5 Limitations of the research

There are some shortcomings inherent to this kind of research because PBL methodology is not mandatory. Since PBL students participate voluntarily they might be more motivated and interested in the subject than the CG students. Therefore it cannot be declared that the results described above are only caused by the PBL itself, they could be caused by an interaction between the PBL methodology and the predisposition of the student. Another limitation of the research is that all the data are self-reported, which means that there can be bias on the answers of students. That could be solved, for example, by contrasting the results of section 4.1 with the final marks of students. However, since the responses to the surveys were anonymous, it is not possible to perform this analysis.

5 The instructors perception of the PBL implementation and outcomes

The preparation and implementation of the PBL has required a greater deal of work than the preparation and delivery of traditional courses, as has been noted in the literature (Dutson et al., 1997, Kamp, 2012). Lecturers are used to the traditional methodologies and changing to new ones requires the preparation of new material, to think of new ways of evaluating the students' performance, and what is more important, to venture into new territory that requires a background that is not always fully developed in academia. In this case, the lecturers had a deep professional relation with the space industry and the European Space Agency from working in engineering projects, and this was not a big burden. In other cases, if instructors don't have enough experience with real engineering projects, this could be an issue.

The instructors' daily workload increased because the students had neither worked in design nor in a PBL before. They were used to an epistemological approach with systematic questioning, where known, proven principles are applied to analyze a problem to reach verifiable "truthful" answers or solutions. Changing from systematic questioning to design or synthesis models conflicted with the students' background; the deterministic, engineering science approach (Dym et al. 2005). This change is difficult for the students who feel uncomfortable in the new context and require significantly more guidance from their instructors. Furthermore, in order to improve the students' communication skills and have them apply engineering fundamentals rigorously, it is important to have a very close follow up of the students work. This requires a higher dedication of the lectures outside the classroom, compared to that required in the traditional methodology.

One of the main issues we find in our school is a low participation of students in class, and a low interaction with their lecturers. The PBL methodology has proven to enhance this interaction, and is very rewarding for the lecturers.

Another important issue we found out is the low communication skills of our students. They are neither confronted to having to write technical reports on the work performed, nor to deliver oral presentations. The PBL experience has shown that these skills have to be part of the curriculum.

The team work was initially difficult for the students, but the results obtained in the PBL were good with few exceptions.

The PBL methodology has permitted the application of knowledge to design systems, and to think systems, which have provided the students with skills that are not achievable with the traditional learning methodologies. The lecturers' perception is that the students gain significantly higher performance in thinking about system dynamics, reasoning about uncertainty, making estimates and being creative.

6 Conclusions

Different activities have been performed at UPM related to active learning since the academic year 2009/10, driven by the premise that, in order to encourage student motivation and to improve the results, it is essential to have a more active role in learning. PBL is especially suitable to achieve this, and the results from the surveys conducted along two years indicate that:

- PBL Students feel more confident about their technical knowledge than CG students.
- PBL increases motivation, interest in the subject topics and satisfaction of students (see Green, 1998, Orevi and Danon, 1999, Thomas, 2000, Frank and Elata, 2003 and Kamp, 2012).
- PBL methodology enhances students learning and improves not only their confidence about their technical skills, but also transversal skills increasingly in demand in the business world, that classical methods do not develop (Saunders-Smits and de Graaff, 2003).
- PBL methodology requires more effort and dedication from students than the classical methodology. So, if this or similar methodologies are implemented in several subjects of the same semester, a proper coordination of the workload among them should be done.
- PBL methodology requires more effort and dedication from teachers than the classical methodology. As other authors have pointed out (Dutson et al., 1997, Kamp, 2012) PBL methodology requires the preparation of new material, a continuous supervising of student performance, new ways of evaluation and to have a professional background, not only academic, in the technical areas of the projects.

Students also receive with great interest all kinds of initiatives that involve their active participation in real projects. International projects allow in addition the internationalization of teaching and further encourage student motivation. We also find that working with demonstrator satellites is very motivating for students and allows a wider transmission of knowledge. However, implementing these initiatives involves much more work for the lecturers participating in them.

In general, all educational experiences described in this paper represent a strong motivation not only for students but also for lecturers and staff who participate in them.

Acknowledgements

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- We analyze the impact of PBL methodology in aerospace engineering education
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