An example of Space Engineering Education in Spain: a master in space based on Project-Based Learning (PBL)

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Abstract

This work describes the successful education experience for five years of space engineering education at the *Universidad Politécnica de Madrid* (UPM), Madrid, Spain. The MSc. in Space Systems (MUSE, *Máster Universitario en Sistemas Espaciales*) is a 2-year and 120-ECTS (European Credit Transfer and Accumulation System) master program organized by the Microgravity Institute 'Ignacio Da Riva' (IDR/UPM), a research institute of UPM with extensive experience in the space sector. The teaching methodology is oriented to Project Based Learning (PBL), taking advantage of the IDR/UPM Institute experience. The main purposes are to share the IDR/UPM knowledge with the students and promote their collaboration with several space scientific institutions, both national and international. In the present work, the most relevant characteristics of this master program are described, highlighting the importance of the student's participation in actual missions.

In addition, to offer practical cases in all aspects of satellite development, the IDR/UPM decided to create its own satellite development program, the UPMSats. The latest, the UPMSat-2, is an educational, scientific, and in-orbit technological demonstration microsatellite (50 kg-class) that was launched in September 2020 on-board a Vega launcher (VV-16 flight). MUSE students have participated in all phases of the mission, from design to integration, calibration, and testing, and (at present) in-orbit operation. The construction of a microsatellite, although it exceeds in time the academic duration of the master, has proven to be a very interesting and versatile tool for PBL education, since it provides practical cases at all levels of development. Furthermore, the continuity of the project encourages graduated students to continue their education with a Ph.D. and the collaboration of master and doctoral students. These reasons have made MUSE one of the most successful academic programs in space systems engineering in Spain, with high employment rates in the most prestigious space engineering institutions.

Keywords

Space Systems, Master, Education, Project Based Learning

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Acronyms/Abbreviations

ADCS	*Attitude Determination and Control System*
CE	*Concurrent Engineering*
CD	*Concurrent Design*
CDF	*Concurrent Design Facility*
ECSS	*European Cooperation for Space Standardization*
ECTS	*European Credit Transfer and Accumulation System*
ESA	*European Space Agency*
IDR	*Instituto 'Ignacio Da Riva'*
MUSE	*Máster Universitario en Sistemas Espaciales*
PBL	*Project-Based Learning*
SSEA	*Symposium on Space Educational Activities*
UPM	*Universidad Politécnica de Madrid*

1. Introduction

Spanish universities have entailed a profound renewal in recent years to adapt their study programs as results of the implementation of the European Space for Higher Education. In the case of the *Universidad Politécnica de Madrid* (UPM), this change led to the possibility of developing new official master's degrees.

One of these new master's programs, initiated in 2014, is the MSc. in Space Systems (MUSE, *Máster Universitario en Sistemas Espaciales*), fully devoted to space systems engineering and focused on the space industry needs. MUSE is promoted, organized, and implemented by the Microgravity Institute '*Ignacio Da Riva*' (IDR/UPM), a research and technological center of the UPM named after its founder, Professor Da Riva.

IDR/UPM has a quite large heritage in space systems engineering that started in the late 70s of the 20th century with research on liquid bridges under microgravity conditions. Since then, the IDR/UPM institute has been very present in the aerospace sector, participating in a significant number of activities and missions. Some examples are the CPLM payload for the MINISAT mission [1], the thermal control of the OSIRIS instrument for ROSETTA [2], the thermal control of the balloon-borne telescope SUNRISE [3], the thermal analysis of the NOMAD payload in ExoMars [4, 5], SO/PHI and EPDS in Solar Orbiter [6, 7], or the MEDA sensors in Mars 2020 mission [8].

In addition, in 1995, IDR/UPM initiated its own microsatellite development program. The first one, the UPMSat-1 was launched in 1995 and successfully operated for one year. This spacecraft was the first 100% Spanish satellite and, according to reference [9] is 12th in the ranking of the 272 university-class satellite missions. The second one, the UPMSat-2, was launched on September 2020 in the Vega launcher VV-16 flight and is still operational. The UPMSat-3 is currently under development.

In this context, the wide experience in space systems of the IDR/UPM Institute was organized as a master program within the period 2010 and 2014, and in September 2014 the first lessons of MUSE were given to a selected group of students at the Aerospace Engineering School of UPM. Since then, the main purpose of MUSE [10, 11] has been focused on sharing with students the IDR/UPM institute experience in space research/technology, make them part of the microsatellites development program and other missions, as well as promoting collaboration with several space scientific institutions and companies.

The aim of the present work is to describe the academic design of MUSE and to emphasize the usefulness of using PBL methodologies to train master students. In addition, some insights on the way the development of the UPMSat-2 and other missions have improved the program of MUSE are presented. On the one hand, this project represents a unique framework in which students can participate in actual projects using the skills learned in the master program. On the other hand, the program of many subjects has been modified by the coordinators due to their work on different missions and projects [12].

2. Project-Based Learning applied to master programs on Space Engineering and Technology

Today, there is an increasing interest in the development of new teaching methodologies. These techniques shall be focused on the students learning, making them co-creators of their own education. The idea is to prepare students not only with academic knowledge, but also with some specific skills, such as curiosity, creativity, and collaboration, to prepare them for future success. In this context, Project-Based Learning (PBL) has emerged as an innovative educational technique that offers students the opportunity to gain knowledge and skills by participating for an extended period in real-world challenges, questions, or problems.

Applying a PBL methodology is in general a big challenge for educators, traditionally more focused on the concept of lectures rather than in applying student-centered learning. At universities where professors usually dedicate a part of their workload to research, PBL could be a powerful tool to involve students in the research process. This could give students the opportunity to plan their own research, propose solutions, communicate, discuss their ideas, and evaluate their own progress. Therefore, professors became guides of the learning process, but the motivation is at the students' own.

The application of PBL is especially interesting for master students, who have already acquired a solid theoretical foundation during their degree's studies. In this way, students gain professional experience in actual projects at the same time they learn.

3. Master in Space Systems (MUSE)

The Master in Space Systems of the UPM is a 120 ECTS (European Credit Transfer and Accumulation System) master program designed to provide a practical, updated, and professional approach to space technology. It is fully harmonized according to the UPM regulations regarding admission of students, organization boards, transfer credits from other university programs, Erasmus program, quality procedures, etc.

The academic load of MUSE was designed considering two major guidelines: (1) be focused on a multidisciplinary approach and (2) the use of Project-Based Learning as main learning methodology. Both aspects represent a key factor in engineering education, as students trained within this roadmap seem to be capable of better solutions when compared to students from mono-disciplinary approach programs [13]. This is especially important in space engineering, where PBL has proven to be the best way to combine academic requirements with industry needs.

Regarding general competencies and learning objectives, the MUSE academic program was designed to allow students to gain skills such as: being able to develop original ideas to solve problems in professional contexts; using the acquired knowledge to solve problems in multidisciplinary and less familiar contexts; being able to integrate different knowledge to draw conclusions from a limited amount of information, preserving social and ethical responsibilities; communicating conclusions to specialized and non-specialized audiences; predict and control the evolution of complex situations within a multidisciplinary context related to space systems developing new technologies; be familiar with the quality control systems applied to spacecraft and space engineering, particularly the European Cooperation for Space Standardization (ECSS) standards; and be able to work in group, leading it when required.

The subjects included in MUSE's academic program are shown in Table 1. They are classified in three categories, depending on the learning methodology: (1) Traditional learning (i.e., mono-disciplinary approach based on lectures); (2) Combination of a Multi-disciplinary approach (MA) and PBL; and (3) PBL.

The academic load distribution, in terms of ECTS, is also indicated in Table 1. As it can be noted, an 85% of MUSE academic load is PBL-oriented, with different levels of implementation depending on the subject.

Table 1. Subjects included in the Master in Space Systems (MUSE) of UPM, classified by learning methodology. T: Traditional learning (mono-disciplinary); M: Multi-disciplinary approach; PBL: Project-Based Learning.

Learning methodology	Subjects	ECTS
T	Advanced Mathematics (I, II), quality assurance, space industry seminars	18 (15%)
T+PBL	High velocity aerodynamics, vibrations and aeroacoustics, production, and propulsion and launchers	18 (15%)
MA+PBL	Project management, system engineering, structures, orbital dynamics and ADCS, communications, data housekeeping, power systems, test and verification, space environment, thermal control, space materials, and graphic engineering	52.5 (44%)
PBL	Case Studies (I, II, III) and Master Thesis	31.5 (26%)

In addition, four subjects are specifically oriented to PBL: Case Study I, II, III, and the final project (i.e., master thesis), in which students are encouraged to work in a space engineering project, sometimes carried out in national and international aerospace companies and institutions. These subjects, that are distributed along the 2-year program (Case study I in the 2nd semester; Case Study II in the 3rd; Case Study III and final project in the

4th), are focused on increasingly detailed aspects of the design of space systems. Therefore, they provide students with the opportunity to delve into a specific topic: from acquiring a global vision of a space system and its development process, to focusing on the preliminary design of some relevant subsystems or even going into detailed design.

The next section describes the applications of PBL to MUSE subjects. Although only a few examples are presented, they represent well what is carried out in almost every subject of the master program.

4. Examples of PBL application in the MUSE subjects

4.1. Space Systems Engineering and Project Management (1st semester)

Within the subject Space Systems Engineering and Project Management, concepts related to the new trends in space mission pre-design and feasibility phases have been included [16]. Between these concepts, the Concurrent Engineering (CE) or Concurrent Design (CD) is emphasized, which can be defined according to the European Space Agency (ESA) as “a systematic approach to integrate product development that emphasizes the response to customer expectations”.

The IDR/UPM Institute has its own Concurrent Design Facility (CDF), which includes the technology and resources needed to perform parametric studies with the objective of finding a mission solution that fulfils a set of technical requirements. Through this subject, students are guided in a Concurrent Design process within the CDF [17] (see Figure 1). A mission is proposed each year, depending on ongoing projects, so a preliminary design is requested as a result of the work. The students are divided into two or three teams, each one of them performing the same mission design. This makes it possible to do a comparison exercise between the different solutions proposed by the teams when the design process has ended.

In this context, students of MUSE have participated in different missions and challenges. As some examples, they participated in the 1st ESA Academy Concurrent Engineering Challenge in 2017, with excellent results, performing a phase 0/A design for a lunar mission (Figure 1). In addition, some mission designs have also been performed within the NANOSTAR project [18], funded by INTERREG-SUDOE through the European Regional Development Fund (ERDF). NANOSTAR aims to develop a collaborative platform in Europe for hands-on nanosatellite education and training in space engineering. The mission designs are articulated as challenges between international universities, so students have the opportunity, not only to be trained in practical aspects of Concurrent Engineering discipline, but to interact with international students and share their knowledge and experiences.

Figure 1. MUSE students and professors in the IDR/UPM CDF during their participation in the 1st ESA Academy Concurrent Engineering Challenge.

4.2. Space Structures (2nd semester)

The UPMSat-2 structural design [19] is presented as a case study in the practical lessons of the subject Space Structures. In this subject, students are trained in the use of usual structural analysis tools (such as Nastran/Patran© or ESI’s VAOne software) to then apply the acquired knowledge to a practical case.

They must design a 50-kg finite element method model of the UPMSat-2, as is shown in Figure 2, that can meet the specified structural requirements. Each group must decide between different configuration options such as: material, geometry and thickness of primary and secondary structures, dimensions, quantity, and placement of internal and external stiffeners, etc. The design is then iterated to develop an optimized design in terms of mass.

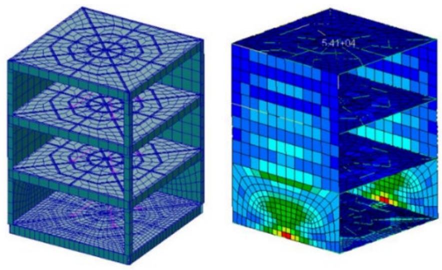

Figure 2. Finite element method model of the UPMSat-2 and structural analysis results obtained by MUSE students.

The developed models are analysed under the same load levels as those used for the calculations carried out in the UPMSat-2 development to verify that the structure will be able to endure the vibrations and noise produced during launch.

4.3. *Orbital Dynamics and Attitude Control (3rd semester)*

The subject Orbital Dynamics and Attitude Control introduces the most relevant aspects of the orbital dynamics needed for the understanding of the functionality of the orbit and attitude control subsystems in a space vehicle. The IDR/UPM Institute has a wide experience in the development of ADCS simulators, including:

- Models of environment and ephemerides.
- Orbit propagators, attitude perturbations.
- Different sensors and actuators models.
- OBC models, including control laws and attitude determination.

The UPMSat-2 ADCS model [20] is used as a basis for teaching students the different parts of an attitude simulator, so that they can test different attitude controls.

As project for the course, students are encouraged to build in small groups a functional Arduino-based attitude control capable of orienting a CubeSat-like platform towards a light source (see Figure 3). Hardware provided to students includes an Arduino UNO kit (with resistors, wires, board, etc), photodiodes and photoresistors as sensors and a servo motor as actuator.

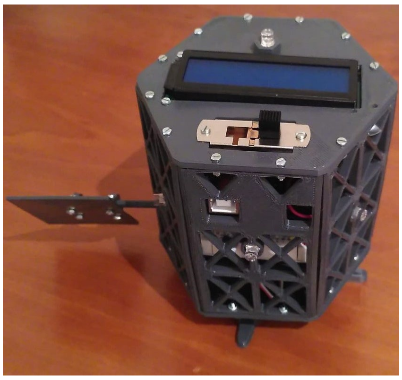

Figure 3. One of the satellites built by the students in the 2021-2022 academic year

Students must model and characterize the various control components, choose their type, quantity and placement, and build the satellite platform (many groups opt for 3D printing). Finally, they design and implement the control law in the Arduino and demonstrate the ability of the satellite to measure the direction of an incident light and orient itself towards it.

5. Discussion and Conclusions

Space science and technology is a field in constant evolution and subjected to the development of new techniques and concepts. This fact should be transferred to universities, updating their teaching models accordingly. The UPM is focusing their effort on the development and use of new and innovative educational tools and programs, in a search for improvements of their student's qualification. Since the end of 2014, the IDR/UPM institute, through the development of its Master in Space System's (MUSE) program, has been using PBL has main learning technique. The academic results obtained during this 7-year period have been very good and the conclusions extracted from students interviews and surveys have shown great student satisfaction. In addition, almost 100% of MUSE students show a high motivation during their participation in the different proposals and projects. Some positive aspects have been identified:

- A significant percentage of MUSE students are interested in or have begun their Ph.D. studies.
- Many students from MUSE are receiving fellowships from departments of other universities.
- A high number of MUSE students have been contacted by companies from space sector even before finishing their master studies.

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