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Research-Based Learning: Projects of Educational Innovation within MUSE (Master on Space Systems) Academic Plan

ABSTRACT

In a search for improvements in their academic plans, most universities are focused today in the development and use of innovative educational programs. Within the different possible innovative educational techniques, Research-Based Learning (RBL) is focused on the generation of didactic experiences based on the scientific method (question formulation, search for answers and solutions, resolution of problems and analysis of results). This method allows engineers and researchers to face new problems through the search of innovation and novel solutions to the problems, out of the common standards. The inclusion of the scientific method within the academic plan of the master's degree in space systems (MUSE) of Universidad Politécnica de Madrid (UPM) is carried out through the definition of study cases. These study cases and the RBL employed methodology supports the theoretical contents of the other subjects included in the MUSE's academic plan. In the Microgravity Institute 'Ignacio Da Riva' (IDR/UPM), different lines of research have been developed to involve students into space projects. Although these lines of research were initially related to the PhD at UPM, the increasing interest among the bachelor and master students on research and projects involving the most advanced engineering techniques, prompted the IDR/UPM academic staff to offer some specific projects to their Master student. Among them, the educational innovation RBL project PIRAMIDE was recently stablished. The subject areas included in this project are related to several space engineering fields: (i) System engineering, where students are involved into the preliminary design (phase 0/A) of space missions by using Concurrent Engineering (CE); (ii) On-board computer design, by the selection and study of specific solutions providing novel knowledge in the field of space mission computers; (iii) Smart design methodologies applied to graphic engineering, where students focus their effort in the development of alternative design techniques for space applications, including manufacturing, assembly, and integration processes; (iv) Analysis of power systems for space applications, by studying systems currently employed in the space sector; and finally (v) Design of attitude control systems, where the students are involved in the development and implementation of a simulated attitude control system based on Arduino. The subject areas included in the educational innovation experience described here are multidisciplinary, the RBL methodology implemented being transversal to several engineering practices. These characteristics allow their application to other fields different from space engineering. The learning concept presented here leads to an increase in student's motivation by involving them in actual research projects that support the theoretical concepts, by mixing theory with practical knowledge. Throughout the research experience, students acquire and outstanding set of high value tools for their future professional life and, in addition, the use of RBL leads to an increase in the teaching quality.

Keywords: Research-based learning, working methodologies, educational innovation, space engineering, concurrent design.

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Introduction

In the last years, Spanish and most part of the European universities have entailed a profound renewal as a result of the European Higher Education Area (EHEA) implementation. The improvements of the resources that are available at the university, as well as the continuous updates in teaching methods have shaped an environment of a continuous search for new educational innovation programs (Hoffman, J., & Pearson, P. D., 2000).

In the case of the *Universidad Politécnica de Madrid* (UPM), this change led to the possibility of setting up new official master's degrees. One of them is the Master's Degree in Space Systems[1] (MUSE, from *Master Univeristario en Sistemas Espaciales*) of the UPM (Pindado, S., et al., 2016). The academic plan of MUSE is focused on space systems engineering and technology, with the aim to fulfill the needs of space industry by training highly qualified professionals. MUSE is promoted, organized, and implemented by the Microgravity Institute '*Ignacio Da Riva'* (IDR/UPM[2]). Over the years, IDR/UPM Institute has worked on many different space projects (Sanz-Andres, A., & Meseguer, J., 2012), such as the UPM-Sat projects (García, A., Torres, B., & Roibás-Millán, E., 2016) (Sanz Andres, A. P., Meseguer Ruiz, J., & Perales Perales, J. M., 2003), the Solar Orbiter (Pérez-Grande, I., et al., 2016), the Sunrise (Pérez-Grande, I., et al., 2011), among others, and it has collaborated with large space institutions such as the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). As a consequence of the IDR/UPM Institute trajectory in the space industry, MUSE academic plan is focused on sharing with the students the wide expertise and experience in space research and technology of the IDR/UPM (and other research groups at UPM that collaborate with this research institute). Through the activities carried out by IDR/UPM Institute, the students have performed internships, supervised assignments, Case Studies (CE) and master's thesis (Trabajo Fin de Master-TFM). Thus, students have had the opportunity to learn through actual ongoing space engineering projects.

A quite large part of the master's program is carried out through Project Based Learning (PBL) (Benedito, J. P., Pérez-Alvarez, J., & Calzada, M. C., 2015). This approach is defined as a new valuable trend in the educational sector to help the students to put their knowledge into practice. PBL is based on presenting actual problems that have an open solution (that is, not unique) to the students, which make them to take decisions.

In this context, and with the aim of following the line of including innovation in the teaching tools employed by IDR/UPM professors, a pilot project based on Research Based Learning (RBL) is being carried out in the present academic year. RBL applies the scientific method to find solutions to the problems presented, in a search for innovation in the solutions and the processes. Essentially, RBL is an educational model that aims to train students in new aspects such as critical thinking and problem solving, enhancing their communication skills and

[1]*Máster Universitario en Sistemas Espaciales* - MUSE, http://muse.idr.upm.es/.
[2]http://www.idr.upm.es/.

technology literacy. RBL is conducted seeking to stimulate constructivism, covering four important aspects: learning to construct the students' understanding, learning through developing prior knowledge, learning achieved through real world experiences, and learning involving social interaction processes and teamwork. Under RBL philosophy, *research* is revealed as a very important mean of enhancing learning quality, as includes components as background, procedures, implementation, research results, discussion and publication. Multiple benefits for the students are expected from the application of RBL in the classroom, as the method itself encourages students' active participation in their learning.
The PIRAMIDE RBL pilot project on educational innovation, which is carried out at IDR/UPM Institute, is described at the present work, the organization of the project within the official academic plan of MUSE and the potential benefits to the students being thoroughly reviewed. This paper is organized as follows: in the next section, the overview of the Master's Degree in Space Systems (MUSE), including its structure and basis, is presented. The motivation, characteristics and exercises proposed in PIRAMIDE are described in *PIRAMIDE: Research Projects Carried out by Master/Bachelor Students for Innovation and Space Development* section. Finally, conclusions are summarized in the *Conclusions* section.

Overview of the Master's Degree in Space Systems (MUSE)

The Master's Degree in Space Systems (MUSE) is a quite recent official program organized and conducted by the IDR/UPM Institute, being fully harmonized according to the UPM regulations regarding admission of students, organization boards, transfer credits from other university programs, Erasmus program, quality procedures, etc. This is a two-year master's degree program with 120 ECTS (European Credit Transfer and Accumulation System) aimed to provide both theoretical knowledge and practical expertise in the space field.

The MUSE academic plan consists of 19 different subjects, 3 Case Studies and a Master's Thesis (see

Table **1**). MUSE subjects are classified according to whether they are monodisciplinary, PBL or can be considered a combination of both concepts. The list with the number of ECTS associated to each subject is also shown in

Table **1**. It is important to highlight the subjects defined as "Case Study", in which the students, guided by a MUSE professor, must develop a research activity regarding a project that is being carried out at IDR/UPM Institute.

Table 1. *Subjects Included in the MUSE Classified by Type of Learning*

Type of learning	ECTS (total)	Subject	ECTS
M	54	Advanced mathematics 1	6.0
		Advanced mathematics 2	6.0
		High speed aerodynamics and atmospheric re-entry phenomena	3.0
		Vibrations and aero acoustics	4.5
		Quality assurance	4.5
		Space industry and institutions seminars	1.5
		Production technologies	4.5
		Space integration and testing	4.5
		Spacecraft propulsion and launchers	4.5
		Orbital dynamics and attitude control	4.5
		Communications	4.5
		Data handling	4.5
M+PBL	34.5	Graphic design for aerospace engineering	4.5
		Space environment and mission analysis	3.0
		Heat transfer and thermal control	6.0
		Power subsystems	3.0
		Space structures	4.5
		Space materials	4.5
		Systems engineering and project management	6.0
PBL	31.5	Case Study 1	1.5
		Case Study 2	7.5
		Case Study 3	9.0
		Final Project	15.0

M – mono-disciplinary learning subject; M+PBL – mono-disciplinary learning subject with some load carried out by Project Based Learning; PBL – Project Based Learning subject.

The number of admissions is limited to 20 students each year, the process being regulated by the UPM official rules. This reduced number of admissions was established in order to maintain educational quality within higher standards, bearing also in mind the size of the IDR/UPM research institute. The admission procedure is based on a review of the applicants' background. In case the number of candidates exceeds the maximum number of possible admissions a round of interviews would be scheduled. Exceptionally, an exam is programmed if the number of remaining candidates still overpasses the aforementioned limit.

MUSE allows students to approach the space industry through Project-Based Learning (PBL) (Brodeur, D. R., Young, P. W., & Blair, K. B., 2002) (Pindado, S., Cubas, J., Roibás-Millán, E., & Sorribes-Palmer, F., 2018), facing real problems and encouraging them to find solutions by trade-off analysis. This methodology is based on the IDR/UPM Institute's own experience in different space projects. To integrate PIRAMIDE RBL pilot project within the official academic plan, a series of *Studies* are performed, each of them harmonized with a subject of the academic plan. Therefore, learners' competencies shall include a strong understanding of basic concepts and methodologies within each discipline, problem solving in creative, logical and systematical manners, and scientific attitude, which covers respect for evidence, honesty and open-mindedness.

Two types of subjects are selected for the application RBL by means of the pilot project *Studies*, one of them initially using only mono-disciplinary learning, and four of them using a combination between mono-disciplinary learning and PBL. The subjects selected are presented in Table 2.

Table 2. *Subjects Selected for the Application of RBL as Main Learning Tool*

Subject	Previous type of learning	Type of learning within the pilot project
Systems engineering and project management (*Study* 1)	M+PBL	RBL
Data management (*Study* 2)	M	M+RBL
Graphic design for aerospace engineering (*Study* 3)	M+PBL	RBL
Power subsystems (*Study* 4)	M+PBL	RBL
Space environment and mission analysis (*Study* 5)	M+PBL	RBL

M – mono-disciplinary learning subject; M+PBL – mono-disciplinary learning subject with some load carried out by Project Based Learning; RBL – Research Based Learning subject.

Each *Study* has been prepared with the main objective of guiding the students through an organized research: formulating a general question, overview of literature and state of the art of the field, definition of the question/problem, planning the research activities, clarifying the methodologies to be used, undertaking investigation throughout the scientific method (i.e., dimensional analysis, selection of control variables, testing, analysis, post-processing and interpretation of results, re-deigns if needed, etc.). Students are also trained in the dissemination and publication of the results of their research: research social networks, selection of journals, attendance to conferences, elaboration of papers, etc.

The *Studies* implementation is intended to develop the student's critical thinking skills and to improve abilities such as interpretation, analysis, evaluation, interference and explanation.

PIRAMIDE: Research Projects Carried out by Master/Bachelor Students for Innovation and Space Development

The university framework provides excellent tools for training and preparing students for their future jobs. However, the usual learning processes still lack the inclusion of one of the main pillars of university activities: research.

PIRAMIDE (*Proyectos de Investigación Realizados por Alumno de Máster/Grado para la Innovación y el Desarrollo Espacial*) is an educational innovation project based on Research Based Learning (RBL). Specifically, the project is focused on the application of the main mechanisms on which a research is based, using the scientific method to learn concepts and to guide students in the acquisition of competencies. It is intended to generate a dynamic framework encouraging the acquisition of research skills by students of the UPM and, particularly, by MUSE students.

The main objective is to use the knowledge transference of the research activities for the students training. The RBL model gives students the opportunity of learning and constructing knowledge from such research procedures as finding information, formulation of hypotheses, collecting data, analyzing, making, and evaluating conclusions, and writing publications or reports.

Other objectives contemplated are the search of a more transversal learning. For this purpose, it should be required to break with the tightness of the contents assigned to a particular subject, in order to find intermediate connection spaces between different subject areas. This connection between different fields can be achieved by the development of projects that require a multidisciplinary approximation. These transversal competencies include bibliographic search and establishment of the background; cross-sectional analysis of problems; application of the scientific method; immersion in different researchers networks (WoS, Scopus, Researchgate, ORCID, etc.); and finally the publication of the results obtained.

The general procedure to apply RBL in a learning is based on several steps: the formulation of a general question; the overview of research literature in the field; the definition of the specific question to be solved; planning of the research activities, clarifying methods and methodologies to be applied; undertaking the investigation; analyzing data; interpretation and consideration of results; and report and publications of the research results.

The PIRAMIDE pilot project has a structure based on three interrelated pillars, for the students to achieve a series of specific skills and competences:

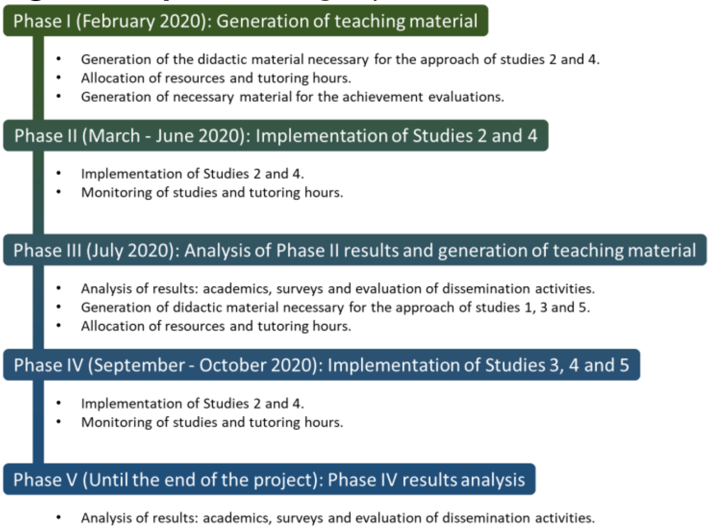
(i) The acquisition of the research skills, encouraging the development of critical thinking. That training should allow students to think, reason and analyze the problem presented in a logical, systematic and creative way. The objective is to achieve the necessary skills to autonomously carry out an organized research (evaluation of the problem and formulation of questions, search and development of solutions, discussion, evaluation of the results and dissemination).

(ii) Collaboration between students of various educational levels (bachelor' and master' degree), professors and researchers. The objective is to combine the two main aspects of university, teaching and research, so that students participate actively in actual research processes and activities.

(iii) The evidence-based education, by which a systematic review of the results of the implementation of the RBL method is established. Some of the indicators considered are the percentage of student success in overcoming the subject, the participation of students in conferences/ publications related to research, and the degree of students' motivation.

For the development of PIRAMIDE, five research *Studies* have been proposed, in accordance with five different disciplines in the space sector, each one of them within the frame of a MUSE subject (see Table 2). These *Studies* have been structured in five stages of development, which are shown in Figure 1.

Figure 1. *Sequential Design of the Education Innovation RBL Project PIRAMIDE*



For the resolution of the problems or questions asked, groups will preferably be created with a combination of students from both master's and bachelor's degree, to involve younger students in the research competitions under the help of students with higher training and experience. To further assist in these concepts, members of two research centers, the IDR/UPM Institute and the STRAST (*Sistemas de Tiempo Real y Arquitectura de Servicios Telemáticos*) group, are also involved in these projects.

In the following subsections, a description of the different *Studies* proposed for the PIRAMIDE project is presented.

Study 1: Design of Phase 0/A of a Space Mission in a CDF

In the last two years, within the Systems Engineering and Project Management subject, concepts related to the new trends in space mission pre-design and feasibility phases (Roibás-Millán, E., Sorribes-Palmer, F. and Chimeno-Manguán, M., 2018) has been included. Between those concepts it is emphasized the Concurrent Engineering (CE) or Concurrent Design (CD), which can be defined according to European Space Agency (ESA) as: a systematic approach to integrate product development that emphasizes the response to customer expectations. It embodies team values of cooperation, trust and sharing in such a manner that decision-making is by consensus, involving all perspectives in parallel form the beginning of the product life-cycle (Braukhane, A. and Quantius, D., 2011).

Space projects are characterized by its complexity and its inherent uniqueness. Its complex nature implies each discipline is strongly related with the others, causing that the impact of any change must be carefully evaluated through all project life-cycle. Therefore, during the first phases of the design, system engineers must consider the multiple design options that should be synthesized, computed, and simulated to select the optimum design option. Concurrent Design facilitates this process through the tasks parallelization, improving the flux of information by working in a collaborative environment.

IDR/UPM Institute has his 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 the technical requirements. Through this *Study*, students are guided in a Concurrent Design process within the CDF (Bermejo, J., et al., 2018). A mission is proposed in base of a set of mission requirements, so a preliminary design is requested as result of the work. Students are distributed in two or three teams; each one of them performing the same mission design, so the results obtained by each team can be compared.

By the implementation of this *Study*, students are trained to understand the mission requirements, transform them into a set of technical requirements and to propose a set of innovative solutions to comply with them. Therefore, students gain the capacity of taking technical decisions, analysing options and reliability and using advanced technological resources.

Study 2: Selection and Study of an On-Board Computer for CubeSat Missions

The typical background of MUSE students is related with aerospace engineering, with limited knowledge of IT and programming. The course on Data Handling is the only one focused on these topics, and therefore has been designed considering the above limitations. Indeed, this constraint generates a need for specific training of students, making it impossible to perform learning only by RBL, with a combination of RBL with mono-disciplinary learning being required.

The main objective concerning students is to make them understand the complexities of developing on-board embedded computers and their software, so that they can communicate with computer and telecommunications engineers in the framework of complex space projects. Consequently, the course is focused on understanding the main principles of the hardware and software architecture of on-board embedded systems, illustrating them with some details on the available technology and the methods used in order to provide insight into how systems are built.

In agreement with the industrial orientation of the master's program, the main objective of this *Study* is to put into practice, in a transversal way, the theoretical contents of the different topics, and apply them to a real-life problem in a satellite mission. In order to do that, the students are asked to select a COTS (Commercial Off-The-Shelf) on-board computer for a given CubeSat mission. Students are required to perform a critical evaluation of different alternatives available in the market. This search for information and products is aimed at reinforcing the contents of the Data Handling course and is expected to allow students experience some first-hand reality of the current market for this type of devices.

The proposed mission is already designed by using the Concurrent Design Facility, and a preliminary analysis of the on-board computer requirements is available. Students are expected to search the Internet and apply the knowledge they have acquired in computer structure, operating systems and real-time systems topics. Moreover, they also use the experience obtained in the embedded system laboratory where, they develop a reduced version of the flight software on a simplified mockup of an on-board computer by using a programming environment and a real-time operating system. This model is based on a cheap, reduced size microcomputer board kit that can be easily acquired and taken home by the students, but it is still quite representative of on-board computers for CubeSat.

At this time, some student teams are carrying out the study. Some of them have found difficulties in applying selection criteria such as the amount of memory needed, the number and type of I/O devices, or the need of a floating-point unit. Class lectures and tutorships have been expanded in order to help them with these difficulties, expecting their understanding of the issues related to on-board computers has improved.

Another consideration is the situation of this academic year due to the COVID-19 pandemic. The fact that this study can be performed at home with a personal computer and an Internet connection has allowed them to complete the work in spite of the lockdown situation in the country.

Study 3: Intelligent Design Methodologies Applied to Graphic Engineering

The main objectives of Graphic Engineering for Aerospace Mechanical Design, taught as part of MUSE academic plan, are as follows:

- To develop the general graphic and technological principles required for the conceptual, preliminary and detailed design of physical space models and space engineering systems;
- To apply quality criteria to these designs and analyze them; and
- To get to know the special programming features on computer design applications in the sector.

The core content of the subject is constituted by: aspects as 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 bachelor’s degree studies are usually insufficient to tackle open-ended design tasks on complex projects such as the space projects. 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. Indeed, a great amount of available information, of many kinds and from many different sources is often found. For a better training of the student, it is necessary to involve him, through active methodologies, in the development of real projects or as close to reality, in order to better develop the subject competencies, while taking account of the aforementioned needs, a teaching experiment was conducted where the classical teaching system was replaced.

This *Study* will be developed from September to December 2020 and will allow students to be taught in Design for Manufacturing and Assembly Integration methodologies (DFMA). Theses methodologies facilitate design processes by prioritizing both, the ease of manufacturing the product parts and the simplified assembly of those parts into the final product, all during the early design phases of the product life cycle (Favia, C., et al., 2016) and taking account the design changes.

As it is known, the design of a space equipment is subject to many changes throughout the phases of its development, from feasibility analyses (phase A) through preliminary design (phase B) to detailed design (phase C), resulting in its final design, manufacturing, integration and testing. In this sense, one of the main challenges, in the activities related to 3D mechanical design, is to flexibly and control all design changes effectively and efficiently. In the current space equipment design process, a significant amount of information and requirements is available from the initial stages, which translates into parameters whose values and number vary and directly affect the design of the equipment.

- The development of the work is established in two complementary objectives:
- Create and evaluate design alternatives, with the aim of generating data that is used in other disciplines of the project.
- Design and create a model configurator (Mock-up Configurator, MUC) for the design of platforms used by other agents for the implementation of equipment and experiments.

The main part of the work involves the generation and parameterization of complex assemblies of 3D mechanical models. The data transfer for the generation of design modifications is carried out by programming design rules and laws with change control (Lau, V., et al., 2014) (Zhu, Y., et al., 2019) (Le Wan, B., et al., 2016). Due to the fact that in many cases the management of the design process is complex, it is necessary to design and to program a user interface that facilitates, on the one hand, the process of generating information and, on the other hand, eliminating the dependence of knowledge on graphics programs, typically used in 3D design, to users who do not have it.

Study 4: Analysis of Power Systems for Space Applications

This *Study* case has been organized by proposing two main problems and different tasks. This *Study* involves the behavioral analysis of two of the elements that conform the power subsystem of a satellite: the solar panels and the batteries. Although they are two different elements, their analysis is based on the same type of procedure, the programming of curve adjustments. The students must analyze and extract worthy information related to photovoltaic systems and Li-ion battery data. In both cases, the information from the UPMSat-2 project (Roibás-Millán, E., et al., 2017) is being used. This is an interesting *Study* that started by the end of March 2020 and it is expected to end by the end of June 2020. A working group composed of six people was assembled during the first months of 2020, supervised by a Professor of the Aerospace Engineering school from UPM:

- 4 Bachelor students of the Aerospace Engineering Degree.
- 2 Ph.D. student working in experimental aerodynamics, space systems engineering and concurrent design.

The aim of this *Study* is different depending on the type of student. Bachelor students are initially focused on learning how to carry out research analysis by:

- Analyzing a problem proposed.
- Making questions on that problem.
- Finding, selecting, and organizing information linked to the proposed problem.
- Decide on the appropriate tools (software) for working towards a solution.
- Reaching a reasonable solution to the proposed problem.

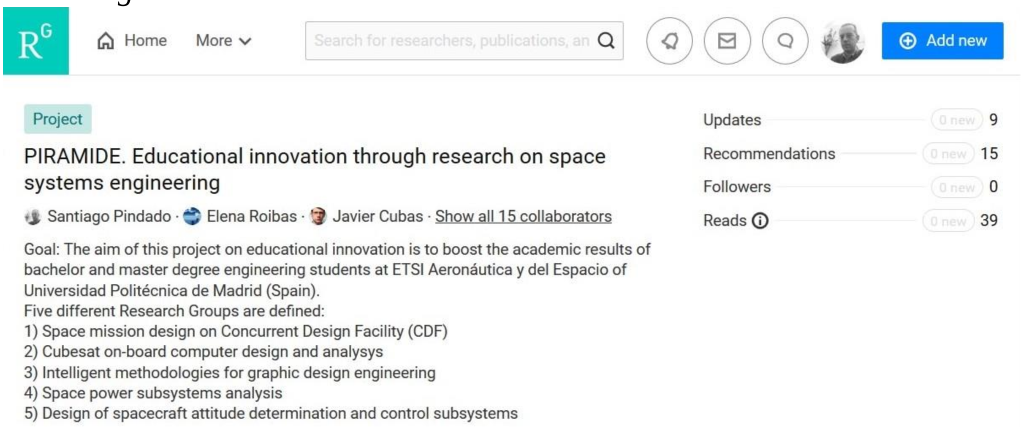
Within this initial phase, Ph.D. students give support to Bachelor students, especially in relation to analyzing and making proper questions on an engineering problem. It should be also remarked that the search for information was also a subject over which the Ph.D. students need to strength their skills. Also, it is foreseen that students will increase the impact of their work carried out by registering in research networks such as Researchgate and ORCID, and by submitting it to conferences and journals.

Concerning the work carried out, the following research lines have been proposed, in relation to the two main problems to be investigated: (i) analysis of the best value for the ideality factor of the 1-Diode/2-Resistor equivalent circuit for photovoltaic systems modeling; (ii) simplified expressions of the Lambert W-function applied to analytical calculations related to photovoltaic performance; (iii) journal list and index-base classification related to solar cells/panels modeling; and (iv) analysis of the UPMSat-2 battery performances. At the moment, this *Study* has produced several results:

- Bachelor students have registered and created their profiles in Researchgate and ORCID (see Figure 2).
- Bachelor students regularly post their partial achievements in a Project created in Researchgate.
- Ph.D. students have supervised the work and the results obtained by Bachelor students.
- Two papers have been accepted at the 20th IEEE International Conference on Environment and Electrical Engineering.

- Bachelor students are supervising their fellow students in small partial tasks (to be solved in around one week).
- A paper related to the work carried out on photovoltaic performance models is being prepared. The following tasks have been assigned:
  - One of the Bachelor students is responsible for managing and supervising the different partial calculations carried out by his/her fellow students, in order to include them in the paper template properly.
  - The Ph.D. students are responsible for checking the results and writing and correcting the text of the manuscript.
- Another paper related to the journal's classification is also being prepared.
  - One of the Bachelor students is responsible for gathering the information from his/her fellow students, and to organize it in an excel file.
  - One of the Ph.D. students is responsible for writing the manuscript and assigning different tasks (references, graphs…) to the other students.

Figure 2. *Project PIRAMIDE Page Created and Managed by Study 4 Students in Researchgate*



Finally, it should be also remarked the list of new resources and skills the people working in this *Study* is planned to gain: Software (Matlab, Mathtype, Mendeley…), research management (task assignment, use of deadlines, results evaluation and organization, possible recalculations after checking the results…), paper writing (organizing ideas within the text, proper use of figures and tables, correct style in relation to mathematical expressions…), paper publishing (selection of the proper journal, use of templates, JCR and SJR classification, revising a manuscript…), Networking (ORCID, Researchgate…).

Study 5: Design of an Attitude Determination and Control Subsystem

In this *Study*, which is linked to the subjects Orbital Dynamics and Attitude Control and Study Case I of the MUSE's academic plan (Pindado, S., et al., 2016), students will acquire practical experience in the design of attitude control subsystems.

The attitude control subsystem of a satellite consists of multiple elements (sensors, actuators, computers, data acquisition boards, etc.) that interact with each other through control laws, filters, etc. The complete operation of the control requires the integration, modeling and development of the algorithms, which is carried out in various stages and requires prior planning. The challenges of each step are easier to understand when students face a real project. To emulate this process, the Arduino development boards are an ideal element (Sobota, J., et al. 2013) (Hertzog, P.E. and Swart, A.J., 2016), since they allow obtaining measurements, processing of results, algorithms implementation and the command of actuators. Nowadays, their wide diffusion allows them to be employed even in industrial projects. Furthermore, they are compatible with design control tools such as Matlab-Simulink (Pires, V.F. and Silva, J.F.A., 2002).

In this *Study*, students will be divided into work groups of 3 to 5 components. Students will have to develop and implement a simulated control subsystem, applying the knowledge acquired during the master's degree. Each group will carry out the stages of assembly; design of the control algorithm; and implementation of the subsystem. This will include sensors compatible with Arduino (such as photodiodes, magnetometers, IMU, etc.); simple actuators (motors, inertia wheels, etc.); an Arduino board and the electrical elements necessary to build a small attitude control.

In a first stage of the *Study*, the project will be included in the subject Case Study I (see

Table **1**). The problem that will be proposed to the students will be an adaptation of a Challenge developed by the Universidad Carlos III de Madrid (UC3M) for the students of universities participating in the project NANOSTAR (Lubián-Arenillas, et al., 2019), among which is the UPM. This example includes the Arduino, solar sensors, a step-by-step engine as an actuator and a 3D printed platform that simulates the structure of the satellite. Lessons learned in this *Study* will be used to improve the exercise and provide it with contents more related to attitude control, additional sensors (magnetometers, IMU), and additional actuators (reaction wheels). This improved version of the exercise will be included as a base exercise for the Orbital Dynamics and Attitude Control subject in subsequent years.

The work of the teams will be to develop the necessary filters and algorithms for the control and targeting of the system and implement them on the development board. The resources used by the students to carry out the task include: the software licenses offered by the UPM (Matlab, Simulink, etc.); Arduino boards; the necessary electronic material; and the supervision and monitoring of the teaching staff and Ph.D. students.

The task will be evaluated at the level of theoretical and practical results. On the one hand, the work will be evaluated through a written report and oral presentation of the results. Furthermore, the RBL approach of the activity will allow evaluation by results, verifying the correct operation and pointing of the subsystem.

Conclusions

Science and technology are fields in constant evolution and subject to the development of new techniques and concepts. Therefore, those fields rapidly lead to the provision of information, either the source of the problem or its essence. Future professionals in the aerospace field must be able to carry out a correct use of information through evaluation on the available data. The evaluation abilities and the decision-making processes require critical thinking, being the later one of the initial factors needed for the emergence of creativity and innovation.

As responsible for the training of future professionals, most universities are focusing their effort in the development and use of new and innovative educational tools and programs, in a search for improvements of their student's qualification.

Procedures of RBL enable students to be equipped with deductive, inductive, reflective, critical and creative thinking abilities, to be capable of dealing with more complex problems. Throughout RBL students not only receive information from the professor or the lecturer. This technique allows students to participate in their education so learning is an active process of learning, to find and built knowledge, making them able to find and build knowledge with research activities.

PIRAMIDE, a pilot educational innovation project based on RBL is presented in this work, carried out by the implementation of a series of cases, named *Studies*, where students are asked to formulate a problem, undertaking a research to solve it and finally, to extract conclusions of their results.

Two of the *Studies* proposed have been carried out in the present academic course 2019/20 (*Studies* 2 and 4), remaining the other three for the coming academic year 2020/21, in order to adapt the pilot project to the academic plan. The studies performed show that when students are involved in solving problems, they felt as an active part of their learning. Indeed, students experience what it means to have a role in the effort to find a solution and therefore, they come across and learn how to work in a real research environment.

Excellent results are being obtained from the students work, some of them are being presented in international conferences and two publications in journal are being prepared.

As future works, the three remaining *Studies* are expected be developed from September to December 2020, a set of interviews and surveys will be prepared to evaluate the students' satisfaction and a manual of good-practices for the implementation of a RBL program are being prepared.

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