Analysis of results from PIRAMIDE educational innovation project

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***Abstract*-** PIRAMIDE aimed at boosting academic results from Bachelor and Master students by doing research on space engineering. This project was carried out by professors from the IDR/UPM Institute and the STRAST group. The program was structured into five different case studies: 1) design of a space mission (phase 0/A) in a Concurrent Design Facility (CDF); 2) selection and study of an onboard computer for a CubeSat mission; 3) intelligent design methodologies applied to graphic engineering; 4) analysis of power systems for space applications; and 5) design of a spacecraft Attitude Determination and Control Subsystem (ADCS). In the present work, the results of conducting five student surveys for each of the case studies and a faculty survey are analyzed. In addition, some critical analysis is included with the lessons learned that might help design better innovative educational projects in the future.

Keywords: Research-Based Learning, Working Methodologies, Educational Innovation, Space Engineering, Concurrent Design, Space Systems

1. Introduction

The experience students acquire from participating in research projects associated with educational innovation programs is widely known as an effective tool that increases student retention rates and engagement, leading to gains in both academic outcomes, skills, and attitudes (Kuh 2008; Lopatto 2010). A wealth of studies has documented these educational gains. These include the development of intellectual skills such as problem analysis and solving, increased tolerance for ambiguity and obstacles, and improved personal initiative (Bauer and Bennett 2008; Hunter, Laursen, and Seymour 2006; Lopatto 2004), increased critical thinking, communication, and writing skills (Russell, Hancock, and McCullough 2007; Trosset, Lopatto, and Elgin 2008). It has also been documented that students participating in research projects report greater interest in pursuing graduate education or a Ph.D. (Eagan et al. 2013; Lopatto 2007; Russell et al. 2007) and are more likely to engage in scientific careers six years after graduation (Hernandez et al. 2018). In this paper, a first analysis is performed on the results obtained after conducting several surveys to 44 undergraduate and master students in aerospace engineering who participated in the PIRAMIDE educational innovation project, as well as to the six teachers involved, in order to assess the benefits of this academic initiative and to better understand the ways in which experienced teachers guide students who are training to become future engineers.

2. Context

During the second half of 2019, the Universidad Politécnica de Madrid (UPM) held its annual call for grants for Educational Innovation Projects led by the university's teaching staff. The UPM articulates educational innovation through: 1) Educational Innovation Groups (*Grupos de Innovación Educativa* – GIEs). Stable groups of teachers who work in educational innovation techniques and are recognized as GIE. 2) Educational Innovation Projects (*Proyectos de Innovación Educativa* - PIEs). Teaching innovation projects led by teaching staff (belonging or not to a GIE), and financially supported by the university. In the 2019-20 call, the candidate projects had to be framed within 5 possible lines of action: 1) Inverted Classroom, 2) Gamification Activities, 3) Challenge-Based Learning / Design Thinking, 4) Research-Based Learning and 5) Virtual Collaboration.

The PIE PIRAMIDE (*Proyectos de Investigación Realizados por Alumnos de Máster/Grado para la Innovación y el Desarrollo Espacial*; CODE: IE1920.1402-P), was proposed by UPM teaching staff integrated in the Instituto Universitario de Microgravedad "Ignacio Da Riva" (IDR/UPM). The project was granted by the UPM Rectorate in February 2020. PIRAMIDE is a PIE that encompasses five studies through which the aim is to promote research-based learning (Pindado et al. 2021). That is, the aim is to improve the academic performance of undergraduate and master's degree students in aerospace engineering through research-based techniques. The five studies are linked to five subjects of the curriculum corresponding to the Master's Degree in Space Systems (MUSE) and directed by the professors responsible for these subjects.

A. The UPM Master's Degree in Space Systems (MUSE)

The MUSE is an official master's degree program approved by the National Agency for Quality Assessment and Accreditation (ANECA). It is one of the first official master programs (if not the first) not linked to any faculty or engineering school. Its proposal is linked to the legislative change represented by the RD 861/2010, of July 2, which amends the RD 1393/2007, of October 29, which establishes the organization of official university education. This RD 861/2010 establishes the capacity of centers such as the IDR/UPM Institute to be responsible for official master's degrees. The MUSE is based on the experience and research of the IDR/UPM in space systems engineering projects, accumulated since the 1970s with the work of Professor Ignacio Da Riva, the first Spaniard to take an experiment into space. The work of the teachers and staff of the IDR/UPM Institute has materialized in projects as relevant as the development of the Thermal Control Manual of the European Space Agency (ESA) or the participation in space missions such as MINISAT, Rosetta, ExoMars, or Solar Orbiter (Pindado et al. 2016). However, the most relevant space systems engineering projects in terms of their academic dimension have been the satellites UPM-Sat 1 (launched in 1995, it was the first 100% Spanish satellite and the tenth university space mission in History), and UPMSat-2 (launched in September 2020, see Figures 1 and 2) (Pindado et al. 2017). Both weighing 50 kg, they make the UPM the only Spanish university that has been able to develop satellites of that mass to this day.

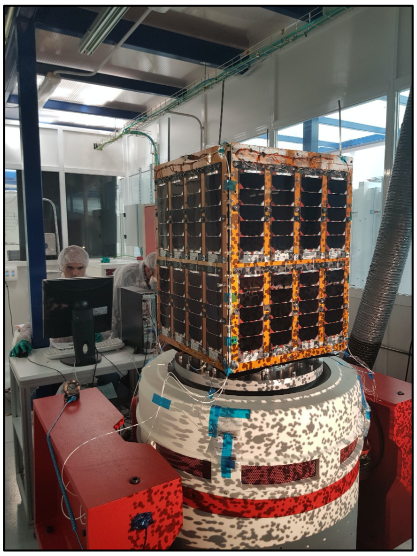

Figure 1. The UPMSat-2 satellite during vibration tests at the IDR/UPM Institute facilities at the Montegancedo Campus (Madrid).

Figure 2. September 2020. Launch of UPMSat-2 aboard the VEGA launcher VV16 mission from French Guiana.

3. Description

This section briefly describes the five studies that comprise PIRAMIDE, and the survey campaign for the evaluation of this PIE.

A. *Study 1. Phase 0/A design of a space mission in CDF (Concurrent Design Facility)*

This study in CDF (Roibás-Millán, Sorribes-Palmer, Chimeno-Manguán et al. 2018; Roibás-Millán, Sorribes-Palmer, and Chimeno-Manguán 2018) is related to the MUSE subject Systems Engineering and Project Management. It was carried out by the 24 students that compose the MUSE promotion called to graduate in July 2022. Two groups were created for this study. A mission was proposed and developed in a first predesign phase, which was completed with the final development of the mission after the revision of the predesign.

B. *Study 2. Selection and study of an on-board computer for CubeSat missions*

This study is related to the MUSE subject Data Management. It was carried out by the 14 students that make up the MUSE graduating class scheduled to graduate in July 2021. Three groups were created for this study. Starting from a CubeSat configuration, a study that included the choice of the on-board computer, the programming and management of the input and output information was proposed.

C. *Study 3. Intelligent design methodologies applied to concurrent engineering*

This study is related to the MUSE subject Graphic Engineering for Aerospace Mechanical Design. It was carried out by the 24 students that compose the MUSE promotion scheduled to graduate in July 2022. The students were divided into 4 groups, and a student was designated in each group to communicate with the teachers. The modular design of a satellite was proposed in which each part and step was parameterized (see Figure 3).

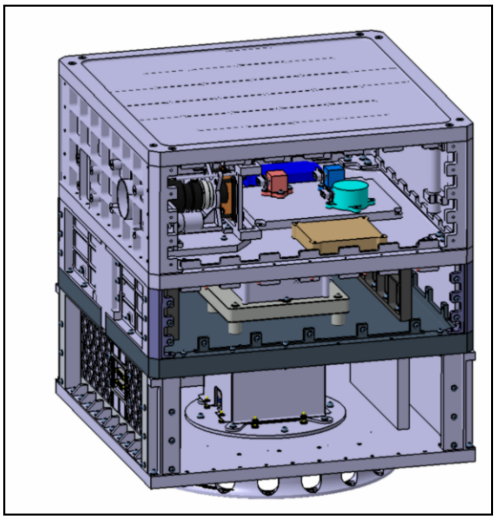

Figure 3. Example of one of the modular designs made by the students of PIRAMIDE Studio 3.

D. *Study 4. Analysis of the behavior of different elements of the power system (solar panels and batteries) of a satellite*

This study is related to the subject Electric Power Generation and Management (Pindado et al. 2018). It was carried out by a group of 4 bachelor's degree students in Aerospace Engineering (GIA), 1 Master's degree student in Air Transport Systems (MUSTA), and 1 PhD student. Initial planning was altered and the battery study was left to rest. However, in exchange, the results of the analyses carried out by the students were published in prestigious journals and international congresses.

E. Study 5. Design of an attitude control subsystem

This study is related to the MUSE subject Orbital Dynamics and Attitude Control. It was carried out by the 14 students that compose the MUSE promotion that will graduate in July 2021. The task consisted in elaborating an attitude control for a satellite pivoting on one of its axes to be oriented towards an incident light (see Figure 4). It was carried out by building a small satellite model controlled by an Arduino. The teacher in charge of this study conducted a survey that reveals both the high motivation to conduct this practical study and the need to improve the teaching dedicated to the joint use of Matlab and Arduino.

F. Design of the PIRAMIDE evaluation survey

To evaluate the results obtained in the five studies (E1,..., E5) that make up PIE PIRAMIDE, a survey was carried out among the students and teachers involved. The digital tool used for this purpose was the open access platform *QuestionPro*. The analysis was structured in 3 groups of students. The MUSE students called to graduate in July 2022 ($N = 24$), group G1, took surveys for studies E1 and E3, those called to graduate in July 2021 ($N = 14$), group G2, focused on studies E2 and E5, and finally there was a third group ($N = 6$), group G3, constituted by students involved in study E4. All these surveys contained the same questions: 14 asking whether they agreed or disagreed with a particular aspect of the project, and one with a list of statements to be rated on a range of 1 to 5 from Strongly Agree to Strongly Disagree.

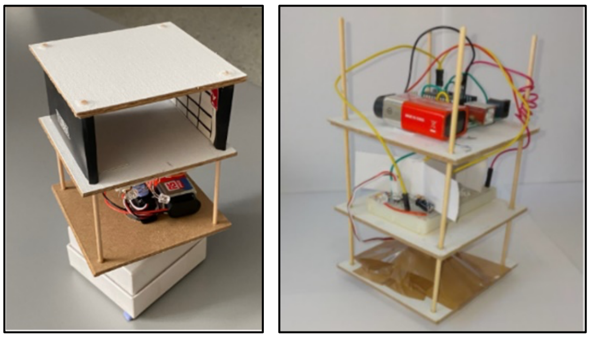

Figure 4. Examples of control systems made by PIRAMIDE Studio 5 students

4. Results

Participation in the surveys was as follows. E1: 17 students (71%); E2: 8 students (57%); E3: 19 students (79%); E4: 6 students (100%); E5: 10 students (71%).

Question 1: *Did the teacher make it clear that this project was part of an educational innovation project?* The results are shown in Table 1.

Table 1: Results of question 1

	E1	E2	E3	E4	E5
Yes	59%	0%	84%	100%	10%
No	41%	100%	16%	0%	90%

Question 2: *Was the work to be done clearly explained by the teacher?* The results are shown in Table 2.

Table 2: Results of question 2

	E1	E2	E3	E4	E5
Yes	100%	88%	100%	100%	80%
No	0%	12%	0%	0%	20%

Question 3: *The work to be performed was reasonable in terms of workload.* The results are shown in Table 3.

Table 3: Results of question 3

	E1	E2	E3	E4	E5
Yes	93%	100%	53%	100%	60%
No	7%	0%	47%	0%	40%

Question 4: *Did you handle bibliography related to the project developed?* The results are shown in Table 4.

Table 4: Results of question 4

	E1	E2	E3	E4	E5
Yes	87%	86%	72%	100%	55%
No	13%	14%	28%	0%	45%

Question 5: *The tutoring work of the teacher was sufficient for the development of this project.* The results are shown in Table 5.

Table 5: Results of question 5

	E1	E2	E3	E4	E5
Yes	80%	86%	89%	100%	67%
No	20%	14%	11%	0%	33%

Question 6: *Do you think that the work developed has helped you to understand and improve your own learning processes?* The results are shown in Table 6.

Table 6: Results of question 6

	E1	E2	E3	E4	E5
Yes	100%	57%	100%	100%	89%
No	0%	43%	0%	0%	11%

Question 7: *Within the project, were you able to develop your own initiatives?* The results are shown in Table 7.

Table 7: Results of question 7

	E1	E2	E3	E4	E5
Yes	67%	14%	94%	100%	100%
No	33%	86%	6%	0%	0%

Question 8: *Do you think your ability to integrate into work groups has improved after this project?* The results are shown in Table 8.

Table 8: Results of question 8

	E1	E2	E3	E4	E5
Yes	80%	29%	83%	100%	11%
No	20%	71%	17%	0%	89%

Question 9: *Have you improved your ability to lead these working groups?* The results are shown in Table 9.

Table 9: Results of question 9

	E1	E2	E3	E4	E5
Yes	47%	0%	61%	100%	0%
No	53%	100%	39%	0%	100%

Question 10: *Have you improved your problem-solving skills after this project?* The results are shown in Table 10.

Table 9: Results of question 10

	E1	E2	E3	E4	E5
Yes	73%	57%	100%	100%	100%
No	27%	43%	0%	0%	0%

Question 11: *The result of the work developed within this project is satisfactory.* The results are shown in Table 11.

Table 11: Results of question 11

	E1	E2	E3	E4	E5
Yes	87%	57%	89%	100%	89%
No	13%	43%	11%	0%	11%

Question 12: *Would you continue working on aspects of this project that may have been left pending?* The results are shown in Table 12.

Table 12: Results of question 12

	E1	E2	E3	E4	E5
Yes	53%	29%	72%	100%	89%
No	47%	71%	28%	0%	11%

Question 13: *Do you think your overall academic performance may have improved as a result of your participation in this project?* The results are shown in Table 13.

Table 13: Results of question 13

	E1	E2	E3	E4	E5
Yes	57%	14%	72%	100%	56%
No	43%	86%	28%	0%	44%

Question 14: *Would you recommend other students to join a similar initiative?* The results are shown in Table 14.

Table 14: Results of question 14

	E1	E2	E3	E4	E5
Yes	100%	57%	94%	100%	100%
No	0%	43%	6%	0%	0%

Finally, the following list of statements (A1 to A7) was made, which had to be rated in a range from 1 (*strongly disagree*) to 5 (s*trongly agree*):

1. A1. I have a better understanding of how to work on research projects.
2. A2. My ability to achieve results autonomously has improved.
3. A3. I am able to better interpret the data extracted from scientific publications.
4. A4. I can better analyze the experimental data and draw conclusions from it.
5. A5. My tolerance for learning difficulties has improved.
6. A6. I have a better understanding of scientific work and how the presentation of results to the community works.
7. A7. I have improved my ability to describe in written form the results of my work.

Table 15 shows the result of averaging the responses from the different surveys.

Table 15: Results of responses to Statements A1, ..., A7 by participants in PIE PIRAMIDE.

	E1	E2	E3	E4	E5
A1	3,86	2,67	3,71	4,67	3,22
A2	3,64	2,50	4,12	4,67	3,78
A3	3,86	2,83	3,47	4,83	2,89

A4	3,43	3,00	3,29	4,83	3,33
A5	3,86	2,83	4,12	4,50	3,89
A6	3,86	2,67	3,94	4,83	3,22
A7	3,86	2,60	3,94	4,67	3,33

The results show first different behaviors in terms of student groups. The highest participation corresponds to G3, while the lowest corresponds to G1. Regarding the questions, the G1 students indicate that the teachers were not informed about the nature of this project in any of the studies in which they participated (E2 and E5). However, it must be said that they were invited to participate in Study E4, and the nature of the project was explained to them. They refused to participate in the study. The satisfaction of this group with the studies carried out also seems to be the lowest. Regarding the studies, Study E2 appears to be the one that has achieved the lowest degree of compliance with the PIRAMIDE objectives (question 13), having the highest level of compliance together with Studies E3 and E4. This result is consistent with the results of Question 15. Finally, the students recommend this type of initiative, although this degree of recognition is lower in Study E2.

The teaching staff survey ($N = 6$) is intended to estimate the degree of satisfaction of the teaching staff through a series of questions:

1. P1. Working on this project has been satisfying.
2. P2. Have you perceived satisfaction in the students involved in this project?
3. P3. Has this project allowed you to improve your teaching content?
4. P4. Would you repeat your participation in a similar initiative?

The results of these questions can be observed in Table 16.

Table 16: Results of the teaching staff survey. Questions P1 to P4.

	Yes	No
P1	100%	0%
P2	100%	0%
P3	100%	0%
P4	83%	17%

Finally, the following list of statements (A1,..., A3) was made, which had to be rated in a range from 1 (s*trongly disagree*) to 5 (s*trongly agree*), the results of which are shown in Table 17:

1. A1. I have been able to integrate this project seamlessly into my academic load.
2. A2. I have received sufficient support/information from the PIE PIRAMIDE management.
3. A3. I have missed more coordination with other PIE PIRAMIDE studies.

Table 17: Results of the teaching staff survey. Statements A1 to A3.

A1	4,00
A2	4,60
A3	3,20

The results of the survey aimed at teaching staff show their satisfaction with the PIRAMIDE project, although the possibility of repeating it in a similar project did not find a unanimous response. It is also noted that there could be some room for improvement in relation to the coordination between the different studies.

5. Conclusions

The most relevant conclusions of PIRAMIDE are as follows:

- The main objective, which is to improve the academic performance of undergraduate/master's degree students through research, has been achieved.
- There are major differences in the approach of the five studies that make it difficult to draw general conclusions.
- Differences are noted in the responses of different groups of students. This result could be an effect of the global pandemic situation unleashed in 2020 and its effects on teaching in technical schools and university faculties.

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