Applying HOL/PBL to Prepare Undergraduate Students into Graduate Level Studies in the Field of Aerospace Engineering Using the Puerto Rico CubeSat Project Initiative

Rachid Darbali-Zamora[1], Nicolas Cobo-Yepes[1], Eduardo I. Ortiz-Rivera[1], Erick E. Aponte-Bezares[1] and Amilcar A. Rincón-Charris[2]

[1]Electrical and Computer Engineering Department, University of Puerto Rico, Mayagüez Campus
Mayagüez, Puerto Rico 00682

[2]Mechanical Engineering Department, InterAmerican University of Puerto Rico, Bayamon
Bayamon, Puerto Rico 00957

***Abstract* – This paper presents an educational perspective into the Puerto Rico CubeSat Project and its objective in preparing undergraduate students into graduate level studies in the field of aerospace engineering. The Puerto Rico CubeSat is a joint effort between the NASA Puerto Rico Space Grant, the University of Puerto Rico-Mayagüez, and other educational entities which promotes space science education. Among its many initiatives lies the Puerto Rico CubeSat project. CubeSats are miniature satellite originally designed for space science exploration. CubeSats are cube shaped micro scaled satellites of low mass and size targeted to perform a wide range of tasks, such as imaging, weather monitoring, gathering information collecting and transmitting data. Each group specializes in a specific engineering field: power, electronics, controls communications, electromagnetics and computing tasked with developing each components of the CubeSat. A project methodology was established and applied to the development of each subsystem of the CubeSat. This methodology consists of a combination of Hands on Learning (HOL) and Project Based Learning (PBL) approaches to help students acquire the necessary skills to succeed in a graduate level environment. The expected impact was not only to encourage and train undergraduate students into a graduate environment, but to develop a teaching platform that can be adapted by other institutions.**

Index Terms – CubeSat, aerospace, HOL, PBL, interdisciplinary research, electrical power supply

I. Introduction

For students to pursue a higher degree of learning, it is evident that alternatives must be developed to help undergraduate students transition into a graduate level environment [1]. Many engineering universities engage in research projects as they play an essential role in student development. For a research project to have a long-lasting effect on students, teaching methods such as Hands on Learning (HOL) and Project Based Learning (PBL) are usually applied [2], [3]. Minds2Create is a research group composed of undergraduate and graduate students from electrical, computer and mechanical engineering. The objective of this research group is to promote research in the fields of electronics, automotive and aerospace systems. The groups research projects include: micromouse robots, quadcopters and small satellites. Minds2Create allows students to bring their projects from design to reality, enabling them to incorporate both technical and hands on skills to complete their projects. To prepare students into the field of engineering, the Puerto Rico CubeSat project was aimed at preparing undergraduate students into a graduate level [4]. The concept was for undergraduate students to combine material attained during courses, with the practical side of engineering. This helps transform undergraduate students into engineers capable of taking on challenges that help develop their skills. HOL/PBL are applied in an aerospace context, introducing basic skills required to succeed in a graduate level environment by developing different CubeSat components [5], [6]. The development of these components was used as an example to validate the HOL/PBL education method. There exist difficulties for an undergraduate to adapt to a graduate level environment. HOL/PBL projects serve as a transition from an undergraduate to a graduate level environment, introducing research concepts that are key to becoming a successful graduate student. To test the success of the HOL/PBL theoretical framework, individual components of a CubeSat were transformed from concept to reality, with a variety of design tools. To illustrate how HOL/PBL plays a role in motivating students into the field of engineering the Puerto Rico CubeSat project was used as an example.

This article is organized in the following manner: section II describes the academic background of the UPRM. Section III gives a general description of the selected aerospace project. Section IV describes the projects approach. Section V describes the project management. Section VI presents the project impact. Section VII shows the obtained results. Finally, section VIII presents the projects conclusions.

II. Academic Background and Collaborations

As part of the Puerto Rico Space Grant Consortium (PRSGC), the University of Puerto Rico-Mayagüez (UPRM) is tasked with the design and development of CubeSat technology. UPRM is a public university located in the municipality of Mayagüez, Puerto Rico. It holds accreditations from the Middle States Commission on Higher Education (MSCHE), the Accreditation Board of Engineering and Technology (ABET) and has been ranked among the top 10 U.S. universities in engineering. One of the most notable educational initiatives in the UPRM is the Industrial Affiliate Program (IAP), a year-long project that allows undergraduate students to work alongside industry affiliates and present their research work in front of industry specialists [7]. This project was sponsored by IAP and provided students research opportunities to learn skills that go beyond the traditional classroom experience.

978-1-5386-1174-6/18/$31.00 ©2018 IEEE

III. THE PUERTO RICO CUBESAT PROJECT

A CubeSat is a miniature satellite originally designed for space science exploration. They are cube shaped micro scaled satellites of low mass and size, designed to perform a wide range of tasks, such as imaging, weather monitoring, gathering information, collecting and transmitting data [8]. Although, initially conceived as an educational tool, they have managed to challenge the concept of traditional satellites and are being recognized for their potential utility by space and research agencies around the world. These CubeSat projects are primarily led by universities and non-US space groups [9], [10]. In most cases government agencies, have sponsored the development of these projects through organizations such as: NASA, National Science Foundation, Department of Energy and Department of Defense, among others.

A CubeSat is powered by solar energy from solar panel modules located on each one of its sides. Solar panels absorb solar energy and store it in batteries to power the CubeSat when sunlight is not available. CubeSats are composed of several subsystems: On-Board Computer (OBC), Electronic power supply (EPS), Attitude Determination Control (ADCS), communication (COMM) systems and a payload, among other structural components. The EPS is a critical component in the CubeSat design [11]. This subsystem supplies electricity to the payloads by transforming the energy generated from the solar panel module array to usable electrical energy. In addition, the EPS charges the battery to provide auxiliary power when needed. The OBC serves as the main computer of the CubeSat and it controls all subsystems. The COMM subsystem receives and transmits information to a ground station. The ADC adjusts the CubeSats orientation. This is completely dependent on the selected CubeSat mission objective. An additional subsystem is the CubeSats physical structure, which houses all other CubeSat subsystems. Each one of these components can operate individually and can be incorporated step by step. Each group takes part in the decisions made to design these subsystems.

The use of CubeSats as an educational tool has been actively explored to promote a variety of engineering fields [12], [13]. Although, the CubeSat platform serves as a PBL educational platform, each subsystem serves as a HOL development tool for students. This allows different student groups to take part in developing a specific subsystem. The successful interconnection between subsystems was the key to develop a successful PBL/HOL experience. To design and build each subsystem, a multidisciplinary/interdisciplinary approach was adopted. For this task to be achieved, it was essential to involve a wide variety of engineering groups, from different disciplines that can tackle different challenges that may occur during the project [14]. The development of accurate design guidelines may help other universities to prepare their own CubeSats platforms.

The Puerto Rico CubeSat was used as a tool that facilitates aerospace engineering education. It was a 2-Unit (2U) configuration, meaning that its dimensions are 10cm × 10cm × 20cm. Two educational concepts for undergraduate student skill development are presented. Primarily, the application of HOL/PBL was used to prepare undergraduate students into aerospace graduate research, providing them with both soft and technical skills needed for graduate level studies. Secondly, a project management strategy that facilitates the learning process throughout the course of the project was presented to promote group activities and teamwork between different engineering fields. This strategy places undergraduate students along-side graduate student that help mentor them throughout the course of the project. The development of the CubeSats EPS and its structural housing are used as an example for the development of both technical and soft skills. Fig. 1 shows a Computer Aided Design (CAD) 3D model of the Puerto Rico 2U CubeSat design, illustrating some of its most vital components. Notice from Fig. 1, the complexity of a CubeSat design, ranging from the variety of electrical and structural subsystems as well as the interconnections existing between them.

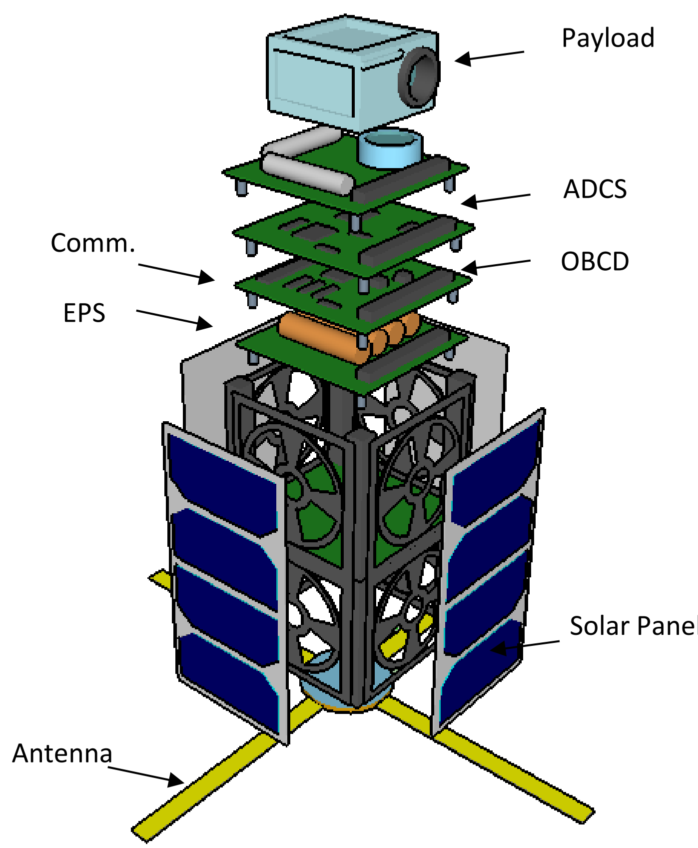


Fig. 1. Standard 2U CubeSat diagram. CubeSats are small scale satellites composed of several subsystems. They are designed to provide easy access to space science and space exploration.

IV. PROJECT EDUCATIONAL CONTEXT AND APPROACH

PBL is a teaching method that gives students the opportunity to participate in research projects that help develop their skills [16]. The objective of applying this method was for students to learn skills required to succeed in a research environment by allowing them to become directly involved in a projects development. To achieve this, another teaching method known as HOL was applied [17]. This method allows students to learn and apply hands on skills relevant to their field. The differences between these two teaching methods was in the way they were implemented. PBL was used as a means for students to engage in a HOL experience. The combination of both these learning strategies results in a project that teaches undergraduate students how to become well organized leaders that can apply technical skills to achieve a common project goal [18].

The combination PBL/HOL also enables students to become engaged in critical thinking scenarios that help in exploring their creativity in a problem-solving environment. Using the Puerto Rico CubeSat project as an educational platform allows students the opportunity to apply theoretical principals taught in courses to real engineering problems. This teaching method was used to prepare undergraduate students to graduate studies in the field of aerospace engineering or related fields by setting the project standards at a graduate level. Students are expected to either have or develop a combination of soft and technical skills [19]. Fig. 2 illustrates a diagram of the minimum technical and soft skills encouraged throughout the course of this project to help undergraduate students prepare for graduate level projects.

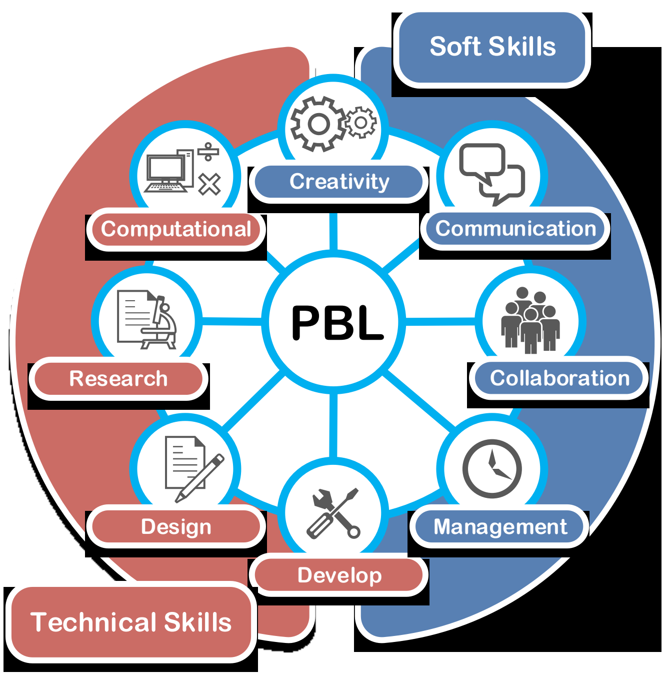


Fig. 2. Hands on skills expected of students participating in the Puerto Rico CubeSat project. These skills are a combination of technical and soft skills students have either developed or will develop over the course of the project.

As an example of how PBL was applied, the Puerto Rico CubeSat Project was used as an example. Special attention was given to the EPS subsystem of the CubeSat to demonstrate the HOL teaching method. The structural subsystem was used to illustrate skill learned related to teamwork and collaborations between undergraduate students. One of the main challenges as well as one of the main objectives of this project was maintaining undergraduate student's interest in the project long enough for their participation to go from the beginning of the project to its completion [20], [21]. For this to be accomplished, the correct work environment must be enforced, not only by ungraduated students but by graduate students, faculty and advisors alike. One important detail to keep in mind was that undergraduate students are full time students and are required to manage between undergraduate research, course work, as well as extracurricular activities. Time management as well as a good distribution of tasks was an essential soft skill. Initially a timeline was developed, listing milestones that must be achieved at the end of the projects duration. A Gantt chart was established to organize the projects expected progress throughout the academic year. This includes the organization of available hours to complete tasks and participate in group meetings.

A key element to prepare undergraduate students was having a good role model to guide them throughout the course of the project, providing an enriching research experience. For this to be accomplished, graduate students take the mantle of graduate advisors to help undergraduate students develop their skills as well as to set an example concerning responsible behaviors in the work environment. Graduate students are vital in accessing each student's strengths, identifying what new skills can be learned and what old skills can be improved. At the start of the project, graduate students provide undergraduate students with basic understanding of the project details, such as functionality and the physical architecture that goes into the project. This includes each physical component assembly and integration into the project. Graduate students assign undergraduate students a wide variety of tasks that encourage them to work alongside each other. This helps promote soft skills related to management, collaboration and communication. These skills are further explored in the project methodology and group structure. Some technical skills that undergraduate students initially learn are focused on research development, performing literature reviews to identify background information and project requirements as well as any mathematical modeling and system simulations to establish a solid theoretical platform.

It was expected that by the end of the project, students had gained all necessary soft and technical skills expected of successful graduate student. The end goal was for undergraduate students to get a taste of what graduate level research was like. In addition, the IAP program expects undergraduate students to provide lectures, demonstrations, workshops, conference presentations, and journal publications to share and document the lessons learned during the project. A project methodology was established to organize student groups. These project groups are meant to apply learned and further develop technical and soft skills necessary to tackle the design process of the CubeSat subsystems.

V. Project Management and Methodology

The Puerto Rico CubeSat project was an opportunity for undergraduate students to participate alongside graduate students and learn new skills that prepare them for graduate level studies. The methodology for this project was based on similar CubeSat project schemes, from other successful universities that have managed to influence undergraduate students. These methodologies use a project group structure composed of three groups: management group, supervisor group, as well as a development group. The management group was composed of university faculty and industrial affiliates. The supervisor group was composed of graduate students tasked with providing guidance to undergraduate student groups. This group oversees the progress made by development group, tasked with the progress of the project.

The Puerto Rico CubeSat project adapts a similar methodology, joining together faculty, industrial affiliates, graduate and undergraduate students. Faculty members and industrial affiliates are involved in the overall management of the project. Faculty participation in the project does not interfere in the student's development process. Graduate students are encouraged to become a part of the mentoring and supervision process. They provide undergraduate students with course work, research articles and related material necessary to accomplish tasks. They also oversee and keep a constant flow of information between all engineering groups. Graduate students are also the bridge between undergraduate students, faculty advisors and industrial affiliates. The project team organization was designed to place undergraduate students in charge of the project. Fig. 3 illustrates the organization of the team members for the Puerto Rico CubeSat project.

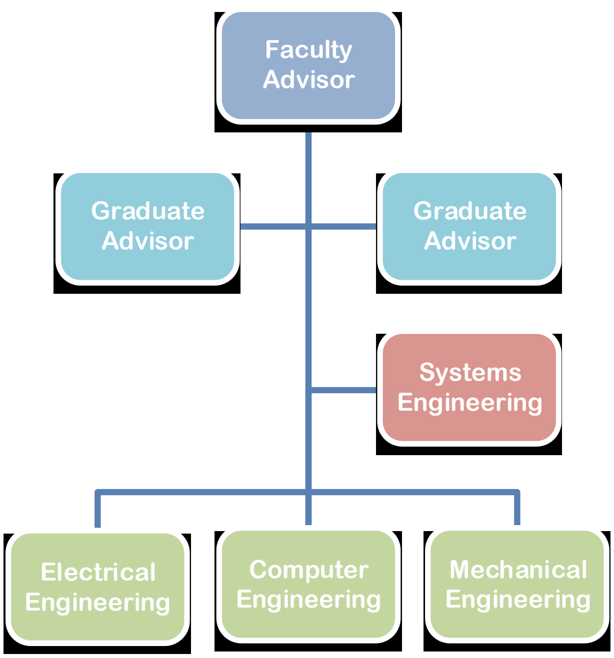


Fig. 3. The CubeSat project team organization. Team includes faculty advisors, graduate advisors as well as the integration of each engineering discipline. The group was organized in a manner that students have the responsibility of leading the project.

This project methodology was applied to the development of the EPS, OBC, ADC, COMM and structural subsystems of the CubeSat. This was an interdisciplinary/multidisciplinary methodology, enforcing collaborations between different engineering departments and fields as well as different institutions by joining together the engineering departments of the UPRM, industry members of the IAP, and aerospace experts from the NASA PRSGC [22]. For the development of each CubeSat subsystem, undergraduate students are assigned to groups based on their academic experience and engineering background. These groups are separated into electrical, computer and mechanical engineering fields to develop different segments of the CubeSat. It was essential that each group possessed basic theoretical knowledge to tackle any engineering challenges that may occur during the project. This teaching method requires teams to work together for the duration of the CubeSat project to learn the necessary technical and soft skills required to complete their tasks.

The teams are managed by undergraduate students, assisted by graduate student mentors and supported by industry specialists. Graduate students are expected to mentor the groups and to help develop necessary sets of skills that play an essential part in the project. The purpose of the interaction was to teach undergraduate students how to adapt to a graduate level research environment [23], [24]. Skills learned by project groups are meant to help them tackle the design, construction and testing process of each CubeSat subsystem. An additional group, known as the systems engineering group, consists of a student representative from each engineering field. This group focuses on tasks related to the interconnections made between all CubeSat subsystems, and how these components interact with each other as well as how they fit in the CubeSat structure.

Electrical engineering undergraduate students mainly focus on the development of the EPS, COMM and ADC. This requires students to have a solid background in circuit design and analysis to assist all other groups in the development of the subsystem PCB design. Undergraduate students from the computer engineering group focus mainly on the OBC and are expected to have enough programming background to assist in the implementation of different types of algorithms necessary for most CubeSat subsystem. These students are prepared to attack any computational problems that may occur during the project.

The mechanical engineering group was tasked with the development of the CubeSat structure and mechanical components. This also involves thermal testing (to validate durability at different temperatures), pressure tests (to emulate conditions present in the vacuum of space) and vibration tests to simulate deployment conditions. Interdisciplinary projects help students develop professional skills in ways traditional courses are unable. These skills help build the bridge between undergraduate learning and the social environment of graduate research. Students are encouraged to document their progress by preparing monthly presentations and progress reports. The idea was to teach them how to present their work to experts, professionals, colleagues and industry affiliates much like graduate students would.

VI. PROJECT STUDENT IMPACT

As an example of how PBL/HOL was applied to the Puerto Rico CubeSat project. The development of the EPS subsystem was used as an example. Students are given the opportunity to design their own PCB layout and electronics [25], [26]. This involves electrical components selection and PCB design considering weight and size limitations. To complete these tasks, undergraduate students use design and simulation tools during the development process. Some of the tools include AutoCAD, Eagle CadSoft, MATLAB/Simulink, NI Multisim and LabView among others. Software tools help bring the EPS subsystem design from concept to reality. Once the CubeSat EPS subsystem was designed, undergraduate students are now able learn and apply hands-on skills for the manufacturing of the PCB. These HOL skills include, soldering components and testing their overall functionality. Fig. 4 illustrates a PCB design made with the Eagle CadSoft software for the final version of the CubeSats EPS.

The Puerto Rico CubeSat project provided undergraduate student with the opportunity to design, innovate and create their own subsystem designs. Fig. 5 illustrate the constructed CubeSat EPS prototypes developed over the course of the project. Fig. 5 (a) shows the first CubeSat EPS prototype designed on a copper clad and traced using a CNC machining tool. The initial prototype, although functional, does not comply with CubeSat standards. Fig. 5 (b) illustrates the second prototype developed on a traditional FR-4 material. Fig. 5 (c) illustrates the final CubeSat EPS design. In a period of a year, undergraduate students have taken the EPS design and transformed it into a robust circuit that complies with both size and weight limitations.

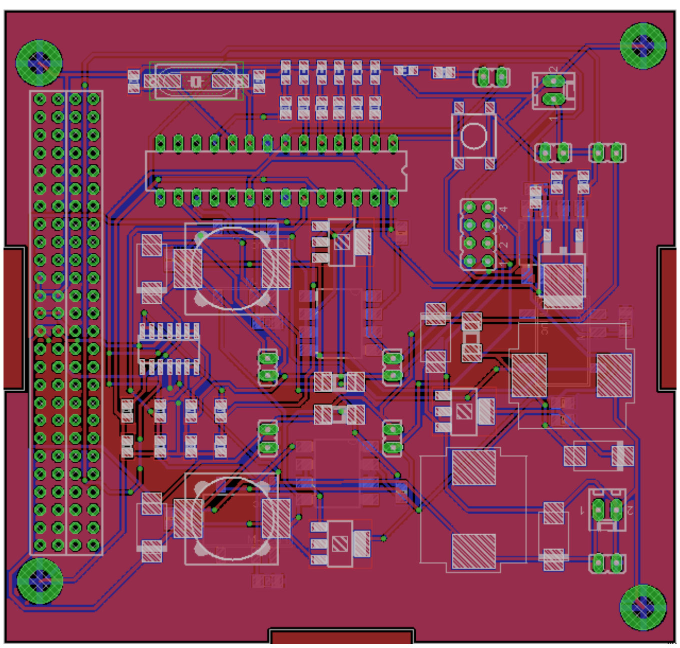
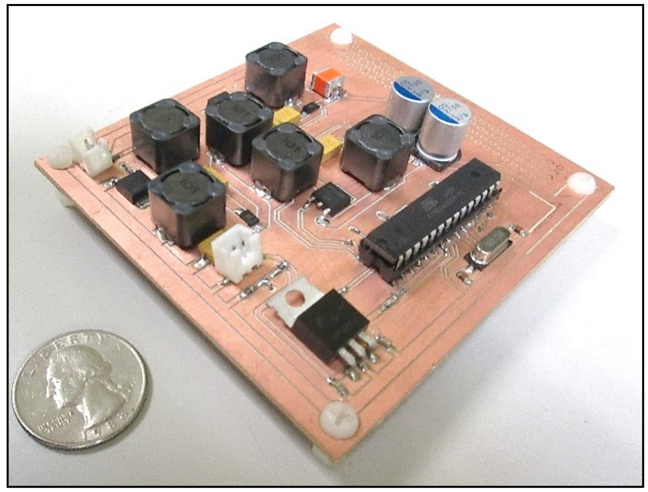
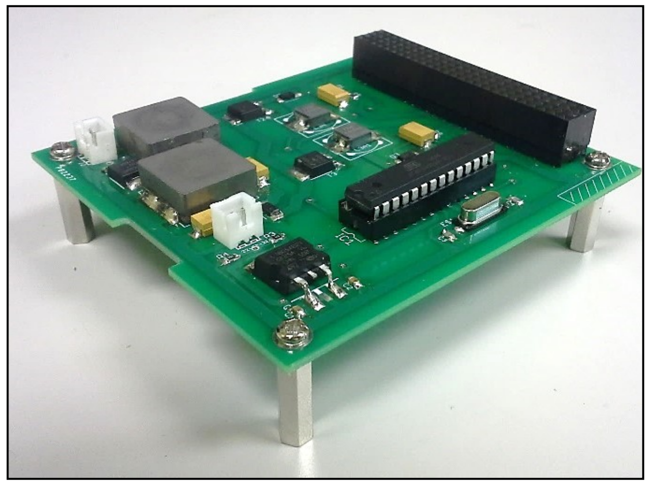


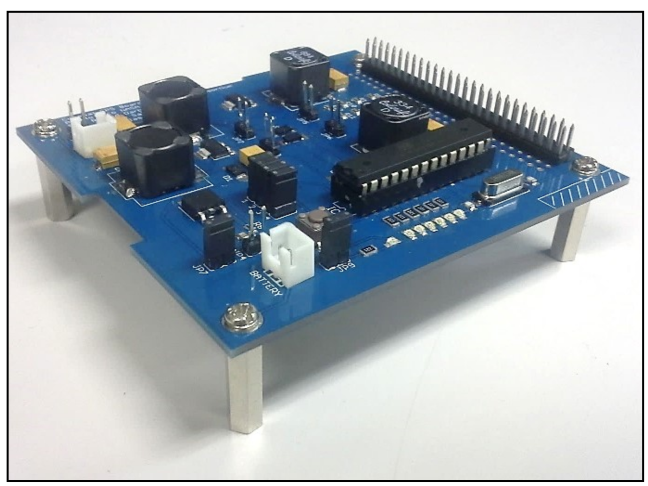
Fig. 4. The 9cm x 9cm PCB design of the CubeSats EPS, developed by the computer engineering team of the UPRM. The project gives students the opportunity to learn new design software that would not normally use in traditional courses.



(a)



(b)

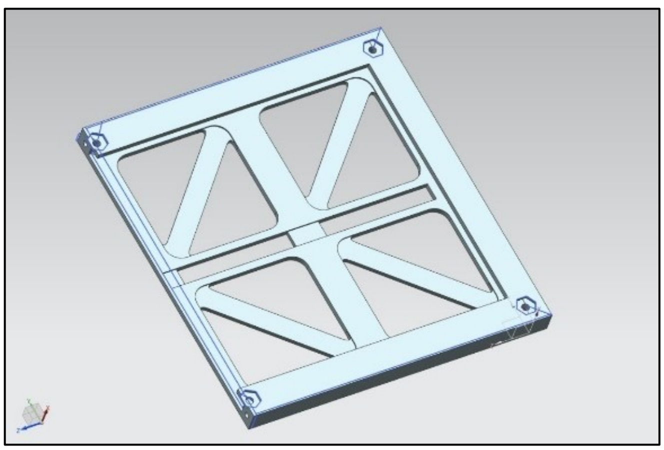


(c)

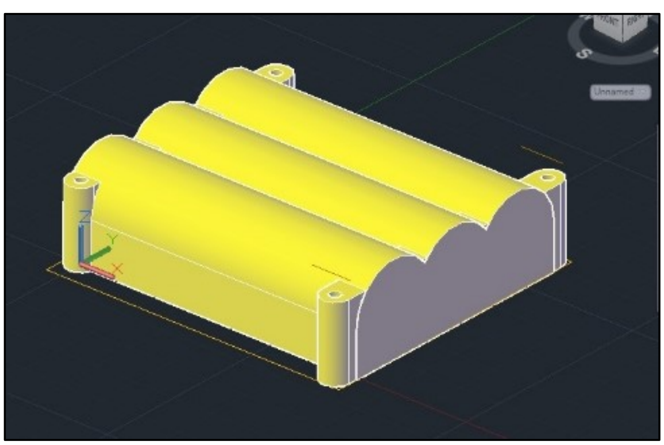
Fig. 5. The developed CubeSat EPS Prototypes. (a) The initial EPS prototype developed for the second semester 2015-2016 with no weight or size limitations. (b) The second EPS prototype developed for the first semester 2016-2017. (c) The third EPS prototype developed for the second semester of 2017-2018.

Two methods are taught for the development of the CubeSat subsystem PCBs. Initially students use a CNC milling machine which traces the circuit paths on a copper clad. Once the functionality of this copper clad PCB was tested, the project can move on to its next phase to improve the prototypes design. This method was used to build initial low-cost prototypes for design validation. Once a definite PCB design was achieved, the PCB was sent to an external manufacturer that uses traditional FR-4. The final process was improvement and optimization of the design, taking into consideration efficiency and component size. The construction and programming of the EPS teaches students technical skills, such as: computation, design, development and construction. Students had a one-year deadline to complete the EPS subsystem. This encouraged soft skills, such as: time management and creativity

To help further develop the creativity in undergraduate students, the development of the CubeSat structure plays a significant role. Not only does the CubeSat structure house the subsystems, but also helps in adapting the solar panel array to the structure. To build the CubeSat structure, several components are designed using CAD Software tools. Fig. 6 illustrates various components of the CubeSat structure designed using Siemens NX and AutoCAD design tools.



(a)



(b)

Fig 6. Developed CAD designs for the CubeSat structure. (a) Solar Panel array housing. (b) Battery pack housing for the CubeSat storage.

The use of 3D printing technology plays an essential role in the development of CubeSat based prototypes, enabling the use of critical thinking skills [27]. This approach has been used to improve student's creativity and problem-solving skills in the past [28]. It was a process that allowed students to take their CAD designs from imagination to reality, encouraging an interactive learning environment. This enables students to develop something tangible, not just a design on a computer screen. The use of a PBL/HOL methodology was applied by exposing students to challenges that will require them to invent and reinvent different CubeSat components, searching for a variety of approaches to solve several design problems.

Since the development of the CubeSat structure houses every other component of the CubeSat, the use of 3D printing encourages communication between students from each discipline, to guarantee that each component fits together perfectly. Some of the soft skills strengthened through the development of the CubeSat structure are: communication, collaboration, management and creativity. Students also develop technical skills such as: design, development and construction. Despite the use of CAD software tools, this approach uses little to no programming, hence there was little progress in the development of computational skills. It was evident that a CubeSat structure required a durable material that could withstand the harsh environment found in earth's orbit. The CubeSat structure was developed using Polylactic Acid (PLA) printed technology to create a quick, affordable and easy alternative to prototyping [29]. As the project progressed, a definite design was achieved, an aluminum frame will replace the PLA printed prototype. Fig. 7 illustrates the developed CubeSat EPS, ADCS and 3D printed battery pack housing.

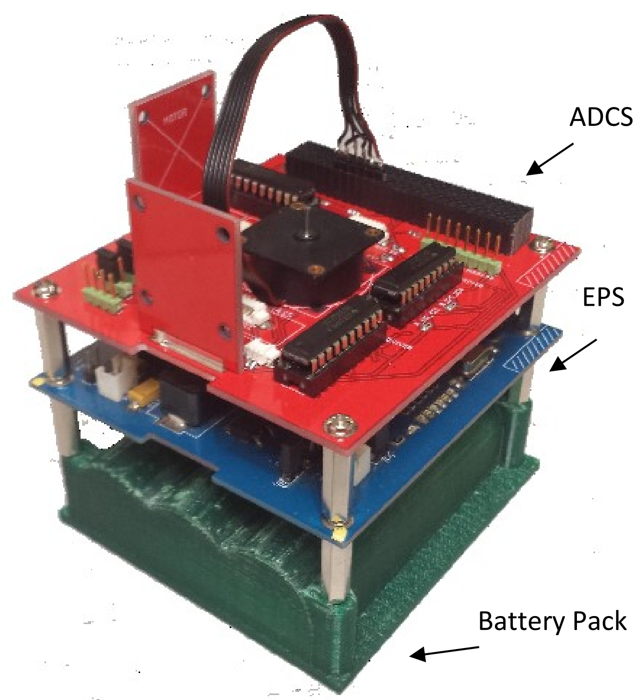
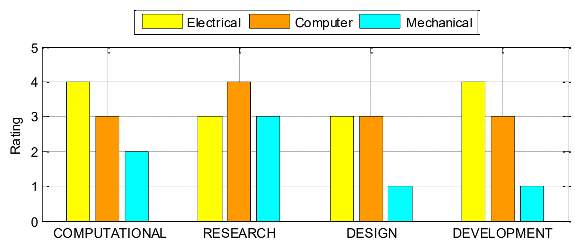


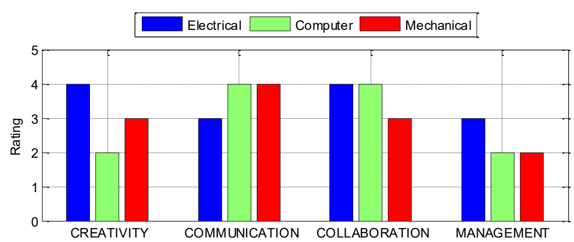
Fig. 7 illustrates the developed CubeSat subsystems. This enables students to familiarize themselves with CAD design tools.

VII. STUDENT OUTCOME AND RESULTS

To understand the progress achieved over the course of the project, one undergraduate student member from each group was given a questionnaire to provide insight into their own personal development [30]. This questionnaire serves as a self-evaluation into each student's personal growth, by helping students assess each of their strong points as well as what skills have improved [31]. For the questionnaire, students were asked to rank their technical and soft skill levels (0 through 5). Fig. 8 summarizes the self-evaluation of the skill level students had before the start of the project. Fig. 9 summarize the self-evaluation of skill level students had at the end of the project.

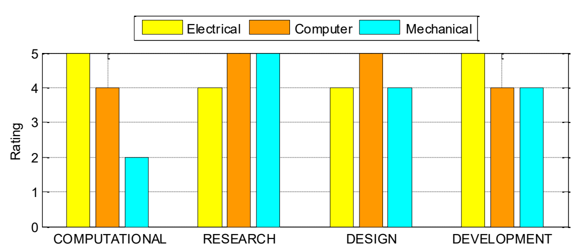


(a)

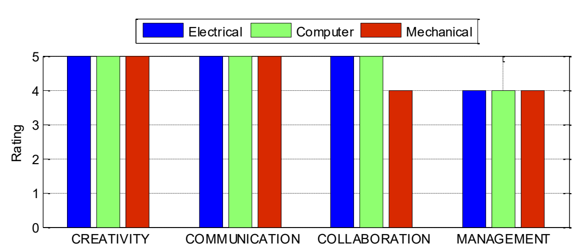


(b)

Fig 8. Self-evaluation questionnaire before project commencement. (a) Soft skills development. (b) Technical skills development.



(a)



(b)

Fig 9. Self-evaluation questionnaire after project completion. (a) Soft skills development. (b) Technical skills development.

Notice from these self-evaluations, that for each student, there was significant improvement in both technical and soft skills. This demonstrates the confidence students have in their own skills after the completion of this project. There was positive feedback from students, expressing how skills developed in this project were unavailable through traditional course work. It was expected that students that were more involved in the structural design of the CubeSat did not show significant improvement in their programing skills. As part of IAP, additional activities, such as oral and poster presentation, helped develop communication skills. In general, students improved their skills to a level that may facilitate the transition to a graduate environment.

VIII. CONCLUSION

This paper describes the educational impact of the Puerto Rico CubeSat project. CubeSats are an interdisciplinary project that involves different aspects of all fields of engineering. This project promotes and encourages undergraduate students into the field of aerospace engineering, serving as an educational tool. The Puerto Rico CubeSat project also employs existing collaborations between the UPRM, the PRSGC, the IAP and other participating institutions, establishing a formal link between these entities. The desired impact of this project was to prepare undergraduate students for graduate studies by engaging them in a graduate research environment. This was achieved by applying teachings methods such as PBL/HOL to help undergraduate students learn a wide variety of soft and technical skills needed to perform graduate level research.

As an example of how PBL/HOL has prepared undergraduate students to graduate level research, the development of the CubeSat EPS and structure was presented. The integration of the CubeSat EPS onto the structural design also indicates the interdisciplinary collaboration between different engineering groups. The inclusion of both these components results in the development of an educational tool that combines PBL and HOL. The outcome was that undergraduate students from electrical, computer and mechanical engineering can take advantage of this educational platform. The intellectual merit gathered by undergraduate students lies in developing a CubeSats educational platform that can be used to accommodate a variety of payloads. This collaboration has influenced a growth in aerospace technologies in universities in Puerto Rico and has helped create ties between UPRM and agencies such as NASA and PRSGC. These efforts have demonstrated that PBL/HOL in an interdisciplinary research project can have a great educational impact on undergraduate students, while at the same time influencing institutions into adopting new tools and teaching methods that can be applied to prepare students into graduate school in the field of aerospace engineering. Results show that after the completion of the project, students demonstrated noticeable improvement in their technical and soft skills. The lessons learned from this project can also be applied to topics outside of the aerospace engineering field. It is expected that undergraduate students interested in pursuing a master's and doctoral degree will base their thesis topic on aerospace applications.

ACKNOWLEDGMENT

The authors would like to acknowledge the support provided by the NASA Puerto Rico Space Grant Consortium (PRSGC) under the grant number NX15AI11H as well as to Sandia National Laboratories (SNL), especially to the Consortium for Integrating Energy Systems in Engineering and Science Education (CIESESE).

REFERENCES

[1]. R. B. Greendyke, "Graduate Level Research from Undergraduate Students: The Lessons Learned by Student and Professor Alike", *32nd Annu. Frontiers in Edu.*, 2002, pp. S4C-1-S4C-6 vol.3.

[2]. J. M. Holgado-Vicente, M. A. Barcala-Montejano, F. Gandía-Agüera and A. A. Rodríguez-Sevillano, "Project Based Learning Activities as a Means of Adapting Conventional Curricula to the Demands of the 21st Century Aeronautical Engineer", *Proc. of the IEEE Global Eng. Edu. Conf. (EDUCON)*, 2012, pp. 1-5.

[3]. R. Martínez, "ETSIT-UPM Experiences in Hands-on Nanosatellite Activities", *Proc. of the 2012 IEEE Global Eng. Edu. Conf. (EDUCON)*, pp. 1-5.

[4]. R. Darbali-Zamora, E. I. Ortiz-Rivera and A. A. Rincon-Charris, "The Puerto Rico CubeSat Project to Attract STEM Students into the Area of Aerospace Engineering", *IEEE Frontiers in Edu. Conf.*, 2015, pp. 1-7.

[5]. C. Zhou, J. D. Nielsen and A. Kolmos, "Foster Creative Engineers by PBL: A Case Study of Student Satellite Project (AAUSAT3) at Aalborg University in Denmark", *2nd Int. Conf. on Wireless Commun., Vehicular Technol., Information Theory and Aerosp. & Electron. Sys. Technol.*, 2011, pp. 1-5.

[6]. M. Yamazaki, "Hands-on Learning of Space Systems Engineering by Using Classroom Pico-satellite HEPTA", *7th Int. Conf. on Recent Advances in Space Technol.*, 2015, pp. 825-829

[7]. M. Velez-Reyes, M. A. Perez-Quinones and J. L. Cruz-Rivera, "The Industrial Affiliates Program at the University of Puerto Rico Mayaguez", *Frontiers in Edu. Conf., 1999. FIE '99. 29th Annual*, San Juan, Puerto Rico, 1999, pp. 13C5/13-13C5/18 vol.3.

[8]. A. J. Gasiewski, B. T. Sanders and D. Gallaher, "CubeSat Based Sensors for Global Weather Forecasting", *US Nat. Committee of URSI Nat. Radio Sci. Meeting*, 2013.

[9]. C. M. Rumpf, A. A. Lidtke, A. S. Weddell and R. G. Maunder, "Enhancing Microelectronics Education with Large-student Projects: Using the Example of the University of Southampton Small Satellite", *11th European Workshop on Microelectronics Edu. (EWME)*, 2016, pp. 1-6.

[10]. L. A. Reeves, "The Canadian Satellite Design Challenge: Building Future Engineering Capability in Canadian Universities", *Commun. Magazine* in *IEEE*, vol.53, no.5, pp.196-198, May 2015.

[11]. M. A. Zafrane, A. Boudjemai and N. Boughanmi, "ALCUBESAT-1, first Algerian univeristy project for educational purpose", *2015 7th International Conf. on Recent Advances in Space Technologies (RAST)*, 2015, pp. 807-812.

[12]. J. Praks, A. Kestilä, T. Tikka, H. Leppinen, O. Khurshid and M. Hallikainen, "AALTO-1 earth observation cubesat mission Educational outcomes," *IEEE Int. GeoSci. and Remote Sensing Symposium*, Milan, 2015, pp. 1340-1343.

[13]. J. Straub, "reviewation of the versatility of the Open Prototype for Educational NanoSats CubeSat design", *IEEE Int. Conf. on Electro Inform. Technol. (EIT)*, 2016, pp. 0586-0591.

[14]. G. Laštovička-Medin, "Nano/pico/femto-satellites: Review of Challenges in Space Education and Science Integration towards Disruptive Technology", *5th Mediterranean Conf. on Embedded Comput. (MECO)*, 2016, pp. 357-362.

[15]. S. E. Palo, D. Gerhardt, Xinlin Li, L. Blum, Q. Schiller and R. Kohnert, "One Year of On-orbit Performance of the Colorado Student Space Weather Experiment (CSSWE)", *2014 United States Nat. Committee of URSI Nat. Radio Sci. Meeting (USNC-URSI NRSM)*, 2014, pp. 1-1.

[16]. T. Andernach and G. N. Saunders-smits, "The Use of Teaching Assistants in Project Based Learning at Aerospace Engineering", *36th Annu. Conf Proc. Frontiers in Edu.*, 2006, pp. 11-14.

[17]. R. M. Rodríguez-Osorio and E. Fueyo-Ramírez, "A Hands-On Education Project: Antenna Design for Inter-CubeSat Communications [Education Column]", in *IEEE Antennas and Propagation Magazine*, vol. 54, no. 5, pp. 211-224, Oct. 2012.

[18]. M. Mosgaard and C. M. Spliid, "Evaluating the Impact of a PBL-Course for First-year Engineering Students Learning Through PBL-projects", *2nd Int. Conf. on Wireless Commun., Vehicular Technol.*, 2011, pp. 1-6.

[19]. J. Macias-Guarasa, R. San-Segundo, J. M. Montero, J. Ferreiros and R. Cordoba, "Tools and Strategies for Improving PBL Laboratory Courses with a High Student-to-faculty Ratio", *Proc. Frontiers in Edu. 35th Annu. Conf.*, 2005, pp. F2C-7.

[20]. R. Chaoming, H. and W. Liu, "Project Based Learning as a Pedagogical Tool for Embedded System Education," *3rd Int. Conf. on Inform. Technol.: Research and Edu.,* 2005, pp. 362-366.

[21]. L. G. Richards, "Work in Progress: Changing Engineering Education: Stimulating Innovation and Overcoming Resistance", *36th Annu. Conf. Proc. Frontiers in Edu.*, 2006, pp. 1-2.

[22]. J. Morehen, C. Wrigley and N. Wright, "Teaching Design Thinking, and Design Led Innovation to Non-designers: A Tertiary Facilitator Multidisciplinary Study", *IEEE Tsinghua International Design Management Symposium*, 2013, pp. 55-63.

[23]. R. B. Greendyke, "Graduate Level Research from Undergraduate Students: the lessons learned by student and professor alike", *32nd Annu. Frontiers in Edu.*, 2002, pp. S4C-1-S4C-6 vol.3.

[24]. N. L. Passos and S. B. Carpenter, "True Undergraduate Research: Foundation for Graduate Studies and Critical Thinking", *Frontiers in Edu. Conf., 1999. FIE '99. 29th Annual*, San Juan, Puerto Rico, 1999, pp. 13C5/7-13C512 vol.3.

[25]. R. M. Peris, M. A. Fillol and L. G. Sánchez, "Discovering Electronics to Aerospace Engineers," *11th Technologies Applied to Electronics Teaching (TAEE)*, 2014, pp. 1-7.

[26]. L. Gil-Sánchez, R. Masot and M. Alcañiz, "Teaching Electronics to Aeronautical Engineering Students by Developing Projects," in *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*, vol. 10, no. 4, pp. 282-289, Nov. 2015.

[27]. A. Bicer, S. B. Nite, R. M. Capraro, L. R. Barroso, M. M. Capraro and Y. Lee, "Moving from STEM to STEAM: The effects of Informal STEM learning on students' creativity and problem-solving skills with 3D printing," *IEEE Frontiers in Edu. Conf.*, 2017, pp. 1-6.

[28]. C. Shemelya, "Multi-functional 3D printed and embedded sensors for satellite qualification structures," *IEEE SENSORS*, 2015, pp. 1-4.

[29]. J. Straub, "Consideration of the versatility of the Open Prototype for Educational NanoSats CubeSat design," *IEEE International Conf. on Electro Information Technology (EIT)*, 2016, pp. 0586-0591.

[30]. M. E. D. Van Den Bogaard and G. N. Saunders-Smits, "Peer & Self-evaluations as Means to Improve the Assessment of Project-based Learning," *2007 37th Annu. Frontiers in Edu. Conf.*, pp. S1G-12-S1G-18.

[31]. E. de Graaff and G. Saunders-Smits, "Peer Evaluation and Peer Review to Support PBL Teamwork," *2nd Int. Conf. on Wireless Commun, Vehicular Technol., Inform. Theory and Aerosp. & Electron. Sys. Technol. (Wireless VITAE)*, 2011, pp. 1-5.