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Interdisciplinary Research for Engineering Skills Development

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ABSTRACT

This work reports the results of an ad hoc interdisciplinary research experience for undergraduate engineering students at the Plasma Engineering Laboratory (PEL) of the Polytechnic University of Puerto Rico (PUPR). The strong features of this experience and their relationship with Accreditation Board for Engineering and Technology (ABET) outcomes are pointed out, and a qualitative description of the results is discussed, in terms of the performance of the students during the experience and after it. An example of the different activities performed by a team of undergraduate students, and their relationship with the ABET outcomes is presented. The undergraduate research at the PEL provides the students with a unique opportunity to practice engineering before graduation through real life problems, innovation, collaboration with other institutions, and presentation of their work for engineering and scientific audiences.

RESUMEN

Este trabajo reporta los resultados de una experiencia interdisciplinaria de investigación para estudiantes de ingeniería, en el Laboratorio de Ingeniería de Plasma (PEL por sus siglas en inglés) de la Universidad Politécnica de Puerto Rico (UPPR). Los rasgos fuertes de esta experiencia y su relación con los resultados esperados por la Junta de Acreditación para Ingeniería y Tecnología (ABET por sus siglas en inglés) son destacados, y una descripción cualitativa de los resultados en términos de la ejecución de los estudiantes durante la experiencia y después de ella. Se presenta un ejemplo de las diferentes actividades realizadas por un equipo de estudiantes subgraduados y su relación con los resultados esperados por ABET. La experiencia de investigación en el PEL provee a los estudiantes con una oportunidad única para practicar la ingeniería antes de su graduación, a través de problemas reales, innovación, colaboración con otras instituciones, y presentación de su trabajo a audiencias de científicos e ingenieros.

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INTRODUCTION

Given that student preparation is the highest goal of an university professor, one starts wondering, how do we get the students to learn the most, in the limited time dedicated to their preparation. Sometimes, you stumble into solutions to that question while trying to achieve other things. In the Plasma Engineering Laboratory (PEL) at Polytechnic University of Puerto Rico, an ad hoc undergraduate research program is in place. PUPR is a small, non for profit, private institution teaching engineering for the least favored population segment in the island. The education is imparted in trimesters, a concentration of 44 hours of classes in 12 weeks. The Plasma Laboratory started as an initiative of Dr. Edbertho Leal-Quirós to perform research in areas related to plasma physics and applications. He had a group of students put together an Electron Cyclotron Resonance Heating Device (ECRH), and had the students perform a few experiments after that (Leonhardt *et al.*, 2001), (Edbertho Leal-Quirós *et al.*, 2005). The experiments were first oriented to the operation of the device, but slowly the laboratory started moving to new topics. Since the ECRH device is custom made, most of the problems involved in its operation and maintenance are unique for this machine. The complexity of the device and the needs for reliable measurements led to the involvement of other professors in the laboratory, performing various tasks related to their disciplines. Here a group of students started working on the microwave signal used for superheating the gas inside the plasma chamber (Gaudier *et al.*,

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2006), and other group started working on instrumentation using electrostatic probes (Meyer *et al.*, 2006). Later on other professors joined the laboratory to perform experiments on the material treatment area. The interdisciplinary nature of the laboratory forced the mechanical engineering students to learn about atom and molecule interactions and ion implantation, electrical engineering students to learn about high vacuum pump operation in order to be able to control them, chemical engineering students to learn about programming, and so forth. Furthermore, the applications of the experiments being conducted made the students aware of a number of current issues in the engineering, social, and environmental domains. Energy, pollution, business aspects of the engineering, and others were topics the students got to learn in order to write their essays and papers. Their need for reading topics that were not taught in formal classes also made them aware of their own need to be continuously studying. Also, their need to be presenting their work to external audiences trained them to put the contents of their work in an attractive, well documented, and easy to understand manner, preparing them to communicate to engineers and people from the scientific community, as well as required them to verbally express ideas and concepts to the public, with a great deal of effectiveness, it must be said. In this work, an assessment of the components of the PEL undergraduate research experience is made, analyzing why it is beneficial for the students and how.

THE EXPERIENCE

The students at the PEL are either invited to work by professors or just come to the laboratory looking for an experience in research. They are selected based on their academic performance (GPA). There is not a rigorous procedure for their selection. They just come and show their grades, if there is room for them, they are accepted. This is so because of the time factor. As mentioned before, the institution packages 44 hours of classes into an 12 weeks term. No need to say that time is the most valuable commodity at this institution. Both, students and professors are always running. The professors (or at least some of them) are always looking for new ways to incorporate additional materials into the courses, comply with the accreditation agencies requirements, grading, preparing, and in top of that, do some research. Hence, a long recruiting process is not an option. The current undergraduate researchers in the laboratory let know their classmates that positions are open, and the students come to find out if they could work in the lab. Once there, a grade transcript is asked for being a GPA over 3.0 generally acceptable. When a student starts working in the laboratory, he is immediately assigned a particular project, either by himself (herself) or with other students. At the same time the student must learn the basics of the operation of the plasma device. The students work an average of 15 hours a week at the laboratory. At that rate, it takes them approximately one term to be up and running with both, their literature review and their plasma operation training. After this term, the students start a number of activities that will depend on the nature of their project. Software projects will require them to learn the particular tools involved, experimental experiences will require them to design the experimental setup and the physical device to be exposed to plasma, measurement project will require them to learn the theory behind both, the physical measurement elements as well as the software required to read from it. After approximately one year of work, the students are required to submit their work to an external conference or meeting, either in form of a poster, a paper, or both. At the same time, the nature of the laboratory requires collaboration among the members of the student teams. No measurements can be taken if the mechanical components of the lab are not working properly. The mechanical components cannot be operated if the control system is not working properly, and so forth. They teach each other, learn from each other, train each other, and complete each others body of knowledge about the laboratory.

THE ELEMENTS

The experience in the PEL is pretty simple. Work in a particular project assigned to the student, reviewing the literature pertinent to the project, performing tasks leading to the accomplishment of the objectives, and presenting the results in a formal fashion. What makes it valuable? Here a few things are listed:

1. The students are encouraged to suggest new solutions for problems either regarding the laboratory operation or their particular project. They are given the freedom to put those solutions into practice, and test how they work.

2. The students are required to design new devices and/or software objects to solve problems regarding the lab operation or their particular project. Usually, the problems are not mainstream engineering, so there are not many places where they can see similar problems.

3. The students are provided with CAD tools to perform the designs devised to solve laboratory related problems.

4. The students are required to present results of their experience. There is no way around it. Presenting their work forces them to learn about the research they performed to a level not achievable by other means.

With these simple items, the experience addresses the following topics:

1. The students are asked to work in real life problems (Jonassen *et al.*, 2006) so they develop a positive, proactive, knowledge based, problem solving attitude to analyze those engineering problems, and are participant of their solution. They are asked to be innovators, to perform quick research on those problems, and to come up with solutions, either new or old (National Engineering Education Research Colloquies, 2007). To do this, the students are informally introduced to formal design techniques and project management techniques (Ramachandran *et al.*, 2002), and are encouraged to talk to other professors and students about possible solutions to the problem at hand.

2. The designs performed by the students must be effective. The devices designed must be working at the end of the experience. Most of the designs performed by the undergraduate students are part of a larger system, and must be integrated either to a particular experiment, or to one of the subsystems operating in the lab. This particular requirement addresses one of the most widely spread problems in engineering education, the application skills (National Engineering Education Research Colloquies, 2007), (Brisk, 1998), or how to make the student to learn applying the knowledge acquired in the courses.

3. The value of the CAD for engineering education is well established (Diefes-Dux *et al.*, 2004), (Stern *et al.*, 2006), (Avouris *et al.*, 2001). Many cases can be found in which the CAD tools enhance the ability of the students to understand concepts and apply knowledge acquired during their course work. The PEL makes an effort to keep current on a number of CAD and analysis tools to be used by the undergraduate students during their research experience. Some of the projects being developed in the laboratory involves the creation of new tools for data handling and measurements.

4. Engineering communication or technical communication (Ramachandran *et al.*, 2002), (Ramachandran *et al.*, 2000), are the terms used by the literature referring to the ability of engineers to express themselves so that the rest of the world to understand them. The communication component is inherent to the undergraduate research experience at the PEL. No student working at the lab is able to get away without presenting at least a poster presentation at an undergraduate research conference or meeting. Emphasis is made in the quality and clarity of the student presentations. They are encouraged to practice their speeches and their materials are reviewed both by their peers, and by the professors at the laboratory. These activities provide with four of the most important skills for an engineer (Dulevičius & Naginevičienė, 2006):

   - Public Speaking.
   - Technical Writing.
   - Talking with people.
   - Working with groups.

If examined under the criteria of the Accreditation Board for Engineering and Technology (ABET), the experience provides mechanisms to attain most of the outcomes defined for the mechanical engineering program at PUPR in the preparation of engineers.

AN EXAMPLE

As an example of the relation of research activities at the PEL with outcomes defined for ABET at PUPR, a particular project currently under development at the laboratory is presented. This project is entitled ”Mechanical Properties Enhancement to Al 6061-T6 after Plasma Source Ion Implantation”, and is used to reflect the engineering design process the students must to perform in order to accomplish their research. The students in this team were requested to research an alternative process to modify aluminum for aircraft structural applications and components (Outcome e). The activities performed by them in this project and their relation with the ABET outcomes defined for the Mechanical Engineering Program at PUPR is outlined below.

1. Literature review of methods and procedures to perform ion implantation (Outcomes i).

2. Familiarization with the Plasma Equipment (physics) existing in the lab. (Outcomes a).

3. Work in collaboration with teams in the Electrical Engineering field as part of a common effort to design the experiments (Outcomes d).

4. Design an experiment to prove the effectiveness of nitrogen plasma source ion implantation (Outcome b).

5. They decided that the surface of the treated materials would be tested for changes on the microhardness, and tensile and compressive strength (Outcomes b and k), and to perform a statistical analysis on the treated samples results. (Outcome m).

6. They had to design the components to place the samples inside the plasma chamber without perturbing the high vacuum environment, and taking into account the characteristic of the plasma to be used, as well the appropriate dimensions to later perform the mechanical tests (Outcome c).

7. This process included the selection of the materials to be used for the test and the use of computer tools to perform the drawings and calculations involved in the process (Outcomes a, k, o, and n).

8. They were also required to present their work in a undergraduate research conference (Outcomes g), where they had to justify the importance of their project. As a results, they had to research further in other methods to do this type of implantation and the impact of this method in the material science (Outcomes h).

Table 1 shows how the Interdisciplinary Undergraduate Research Experience covers, in one way or another, the various outcomes defined by the Mechanical Engineering Department for ABET accreditation (PUPR, 2008) as skills a mechanical engineer should have at the end of his(her) formation.

THE RESULTS

In its 5 years of operation the PEL have received about 120 undergraduate students and a few graduate students performing research. These students got trained in the operation of the ECRH device, and have performed projects to enhance its capabilities, or for an specific research topic. Many of those works have been published in one way or another. Some of them simply as a poster presentation, but a number of them have become a paper presented orally. Articles based on work performed at the laboratory can be seen in the references. However, a number of poster and oral presentations have produced recognitions for the laboratory students in undergraduate research conferences. As a sample:

1. “Plasma Gas Identification using Langmuir Probe”, by Samuel Sanchez. Second Prize in the Undergraduate Poster Presentation Competition at the 2007 More Graduate Education at Mountain State Alliance (MGE@MSA) and Western Alliance to Expand Students Opportunities (WAESO), Denver, Arizona, May 2007.

Table 1.
Coverage of ABET Outcomes.

Outcome	Description	Cover
a	An ability to apply knowledge of mathematics, science, and engineering(s).	X
b	An ability to design and conduct experiments, as well as to analyze and interpret data.	X
c	An ability to design a system, component, or process to meet desired needs within realistic constrains such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability.	X
d	An ability to function on multidisciplinary teams.	X
e	An ability to identify, formulate, and solve engineering problems.	X
f	An understanding of professional and ethical responsibilities	
g	An ability to communicate effectively.	X
h	The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.	X
i	A recognition of the need for, and an ability to engage in lifelong learning.	X
j	A knowledge of contemporary engineering issues	X
k	An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	X
l	Apply knowledge of chemistry and calculus-based physics with depth in at least one of them	X
m	Apply statistics, linear algebra, and advanced mathematics through multivariate calculus and differential equations.	X
n	Work professionally in both thermal and mechanical systems areas including the design and realization of such systems.	X
o	Apply knowledge of contemporary analytical, computational, and experimental practices.	X

2. "Enhancement Of Plasma Nitriding Process To Hardness Stainless Steel", by Ramón Rivera- Varona. Third Prize in the Undergraduate Poster Presentation Competition at the 2007 More Graduate Education at Mountain State Alliance (MGE@MSA) and Western Alliance to Expand Students Opportunities (WAESO), Denver, Arizona, May 2007.

3. "Automation of PUPR Mirror-Cusp Plasma Machine" by Efrain Morales y Omar Molina. First Place in Technical Presentation at the 2007 Engineering Design Competition COINAR (Congreso de Ingenieria y Agrimensura). Universidad Central de Bayamon. March 2007.

4. "Mass Spectrometric Study of Various Coated Targets Utilizing the PUPR-MC Plasma Machine" for NASA Solar Probe Space Mission, by Giovanni Lleonart. First Prize in Technical Poster Presentation. 2006 Puerto Rico Caribe Hilton Conferences in October 2006.

5. "Hydrogen Storage in Diamond Powder utilizing Sodium Fluoride for Fuel Cell Applications", by David Leal-Escalante. Second Place in Technical Paper Presentation.. 2005 ETCC SHPE Philadelphia PA in October 2005.

The list shows the most recent or most relevant recognitions obtained by the laboratory students. Other students have obtained recognitions in various undergraduate research meetings, but for the sake of space, only a sample is included. Needless to say that these recognitions boost up the self confidence of the students obtaining them. All of the students mentioned in the list above either obtained a job (with above average pay) before graduation date, or are pursuing graduate studies, or both. Since 2004, PEL has supported about 120 students in one way or another, both graduate and undergraduate. From these group, 13 (11%) have continued towards graduate studies, and 4 (3%) of them are being hired by Research and Development departments at various companies throughout the U.S., 14% are still studying at PUPR, 2 of them have become professors at two different universities, while the rest are working in diverse organizations. The percent of PEL students continuing toward graduate studies is consistent with the national percent of Hispanic students continuing toward graduate school, even though the population served by PUPR is mostly from a low income bracket of society.

CONCLUSION

The PEL was created with the objective to conduct research in the area of plasma applications and fusion. As a byproduct, the undergraduate students at PUPR have an interdisciplinary research opportunity available right on campus. This opportunity presents them with various of the most valuable experiences an undergraduate engineering student may have:

- Working in real life problems to put in practice engineering skills.
- Freedom to innovate in the solution of those problems.
- Acquire communication skills either in written or oral form.
- Participate in real research in collaboration with other universities and institutions.

These particular skills are addressed in the literature as important for an engineer to acquire by the date of graduation. The undergraduate research experience allows for these skills to be developed in a sustained manner, since the students work in the laboratory for more than one or two terms. Moreover, it allows the students to mature their performing in any of the areas of work, producing a more complete, rounded professional. From the professor point of view, it also produces the evidences required by ABET to certify interdisciplinary undergraduate research and design experiences. The undergraduate research experience at PEL prepares students from various engineering disciplines to function as designers, engineers, and scientists. From other point of view, the experience also enhance the student-faculty interaction mechanisms, by applying a Problem Based Learning element in the curriculum of Electrical, Mechanical, and Chemical Engineering programs at PUPR.

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