

# Research Laboratories and Training Undergraduate Students from the Freshman Level to Produce International Conference-level Publications

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**Abstract**—We present the first results of the teaching methodology applied at the *Universidad de Ingeniería y Tecnología* (UTEC), Lima, Peru, to involve undergraduate engineering students in advanced research projects starting at the freshman year. Students at UTEC start taking mandatory engineering semester projects, similar to Capstone projects, starting on the first semester. Students with good performance and, more important, with a high will to keep learning extra topics, are invited to participate, to learn using a project based learning methodology, in the Research Laboratories led by experienced professors. The successful students start participating in advanced research projects as developers. In this manuscript, we present the case of two students who started learning hardware design, in their freshman year, and by the beginning of the third academic year, their work, which was part of a collaborative project among UTEC, the University of New Mexico and the U.S. Air Force Research Laboratories was presented as an oral presentation, among grad school-level papers, in an international conference in microelectronics. Those students have not taken the courses related to those topics yet, but they are learning how to develop advanced research and development projects. This methodology is being applied with all the students at UTEC and our expectation is that similar results will be reached in different engineering programs.

**Index Terms**—project-based learning, research and developed, teaching methodology

## I. INTRODUCTION

The best way to become an engineer is by doing engineering projects in contrast to the traditional methodology, where science courses are taught deductively. In the traditional way, the instructor first grounds students thoroughly in relevant theory and mathematical models, then moves on to textbook exercises and eventually, gets to real-world applications. Often the only motivation that students have to learn the material, beyond grades, is the vague promise that it will be important later in the curriculum or in their careers [?]. The project-based learning (PBL) method implemented at Universidad de Ingeniería y Tecnología (UTEC) tries to transmit mastery of work-related skills (or competences) rather than command of a particular academic discipline [?]. It is developed with the objective of forming designers and innovative engineers rather than engineers champions in mathematics as it is the major descriptor of the traditional university systems, especially in Peru.

Most undergraduate engineering programs are characterized by having a mandatory engineering project to be developed during the last semester or the last year [1], for example the Capstone projects. By this, the university offers to the students the experience of applying all the knowledge learned during 4 or 5 years (depending on the country, see [2], [3] for examples) in an engineering project. These projects are developed in groups and, sometimes, the projects are more challenging if they are transdisciplinary, which not only involves mixing students from different programs, but also to make the students know and participate, at different levels, in all parts of the project. More exciting projects are those projects related to real needs from industries, which could become sponsors of the students. This model works well and it has been the model used for years to produce good engineering professionals around the world.

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Thus, the university provides to the students the experience of applying all the knowledge taught during 4 or 5 years (depending on the country, a regular undergraduate engineering program lasts for 4 or 5 years, see [2], [3] for examples) in an engineering project. These projects are developed in groups and, sometimes, the projects are more challenging if they are transdisciplinary, which not only involves mixing students from different programs, but also to make the students know and participate, in different levels, in all the parts of the project. Thus, an electrical engineering student has to know about the parts developed by, for example, the student of economics. More exciting projects relate those projects to real needs from industries, which become sponsor of the students. This model works well and it has been the model used for years to produce good engineering professionals around the world.

On the other side of the model, we are witness of how engineering programs lose students from one semester to another. The reasons are different but most of them are related to [4], [5]:

- Funding: students cannot afford the tuition;
- Change of program: students realize that they have made

a wrong decision by choosing engineering and switch to a non-engineering program like administration; or

- Change of the engineering program.

When the students are asked about the reasons to leave the program selected, and their answers are related to the last two reasons listed before, their opinions are associated to: (i) the students get tired of learning theoretical topics without knowledge of why they need to learn those topics or how to relate them with real world engineering problems [4], [5], or (ii) the students think that they need to study a masters or a doctoral program if they want to learn more advanced topics for research and development [6].

Related with the last opinion, most of the advanced research laboratories around the world are part of the grad programs. These laboratories are led by an experienced full professor and other professors, postdoctoral fellows, Ph.D. and M.S. students and external collaborators form the research team<sup>1</sup>. Undergrad students are not common to be found in these advanced laboratories unless they are working in their undergrad thesis or are being trained to join the grad program. However, there are reports about the importance of undergrad research and how this benefits the learning of the students during their studies [7], [8], [9], [10].

To improve the quality of engineers formed and to reduce the number of students leaving the programs, we, at the *Universidad de Ingeniería y Tecnología* (UTEC, ‘University of Engineering and Technology’ when translated to English) have started applying a new methodology to start training students, since they are in the the freshman year, as they are part of a research laboratory. Working together with the Quality Assurance Department and the Management, Arts and Humanities Direction, students at UTEC start taking mandatory engineering semester projects, similar to Capstone projects, starting on the first semester. At the end of a semester, depending on the grade of the project (from 0 to 20), the student receives one project credit. At UTEC, the students must have at least two project credits before they complete 100 credits in their career. These projects are not only fully related to the five engineering programs offered at UTEC (electrical, mechanical, chemistry, industrial and, energy) but also to combine them and to work with non-engineering areas. The students who show a good performance and, more important, with a high will to keep learning extra topics, are invited, or they request, to participate in the research laboratories. The students are trained using a project-based learning (PBL) [11] methodology. Then, the successful students start participating in advanced research projects as developers.

In this manuscript, we present the case of two students from the first invitation to be part of the research laboratories during their freshman year and, after 14 months on working and learning, they presented their first results on hardware design (Towards a FPGA-based Universal Link for LVDS Communications: A First Approach) at the Iberoamerican

conference on microelectronics IBERCHIP [12], in Chile, as an oral presentation. Their learning started with a fun challenge to start applying the PBL method, and then, after having some basic knowledge, as part of a collaborative work among UTEC, the University of New Mexico (UNM) and the Air Force Research Laboratories (AFRL-USA). The topics related to their research are taught in parts in some mandatory courses but those students have not taken them yet.

This case is presented starting with the background about UTEC in section II. In section III, we present the methodology used starting from the invitation to the freshman students up to the presentation of their work in the international conference. In section IV, we discuss the results of this methodology in terms of the students’ performance not only in classes, but also in terms of their soft skills compared to other students: (i) those who did not participate and in the research groups and (ii) those who started in the research groups but left it after some months. Finally, we present the conclusions and future work in section V.

## II. BACKGROUND

Peru is a country full of diversity: geographical, cultural, economic, beliefs, languages, manners, where the needs are understood and responded in different magnitudes and possibilities, but mainly in compartments. Many hypotheses have been raised to such common problems in our country, and in other parts of the world, trying to find a way to come up with solutions. UTEC is a young university, only with undergraduate programs, created by successful CEOs from big companies in Peru with international operations such as Hochschild Mining, Cementos Pacasmayo, Buenaventura (mining company), Credicorp (finances), Ferreyros and Caterpillar, among others<sup>2</sup>. UTEC plans to be a research university and for this, one of the strategies was to create a Research Department with national and international Ph.D.’s, with international experience in research and development (R&D), which were brought to live in Peru. These professors formed their research laboratories having as one of the goals to form a research team, which should include young undergrad students. To make these research laboratories stronger, UTEC has a director from the Massachusetts Institute of Technology (MIT) in its advisory board and active collaboration agreements with international universities such as Harvard University, Purdue University [13], the University of New Mexico (UNM), among others.

To the best of our knowledge, UTEC has developed a new curricular plan in order to train engineers needed by the country and the world, where the education provided is focused with a vision of the formation of a holistic engineer [14]. The opinions of representatives of industry, academia and the experience of other institutions in the country, or abroad, has been considered for the development of the curricular plan, and to define the skills and competencies of future graduates [15], [16], [17], where they all pointed to soft characteristics, skills and competencies that a traditional curricular plan does

<sup>1</sup>See for example the ‘image and video Processing and communication laboratory’ [Online] <http://ivpcl.org/>

<sup>2</sup>Universidad de Ingeniería y Tecnología [Online] <http://www.utec.edu.pe>

not provide as part of their courses: leadership, teamwork, communication skills, creativity, proactivity, among others. Thus, 25% of the career mandatory courses at UTEC are topics of humanities, management, art and languages.

Students at UTEC come from different backgrounds, level of knowledge, cultural and economic situation. For example, in Fig. 1 we show a map of the cities of the 2012 admitted students. It is well known that the quality of the education from inside the country compared to Lima, the capital of Peru, and from private and public schools differs [18]; this has been one of the principal issues in all national<sup>3</sup> and international forums held in Peru. Subsequently, these new admitted students took a new test to evaluate their assessing knowledge through an exam equivalent to the SAT (Scholastic Aptitude Test) test used in USA.

Table I shows the grades of admitted students in each evaluated subject (verbal, arithmetic, algebra and geometry). The lowest grades were in the verbal area (analogies, reading comprehension and incomplete sentences) having an average of 11.78 points, followed by areas from arithmetic, geometry and algebra, the latter provided the best average with 16.44 points over 20. Minimum ratings were between 0 and 6.67 points, while the maximum score reached 17.33 on the area of verbal and a grade of 20 in arithmetic, geometry and algebra.

UTEC also applied a test to know the profile of the admitted students in relation to their personal skills, their learning styles and techniques, study habits, an other variables, that they used. Some aspects of personality characteristics are analyzed as self-knowledge to get a better deal of the the emotional components in stress situations (level of anxiety, depression), or its relations with others (level of gregariousness, assertiveness, competitiveness, opening to values) and other characteristics such as to determine their level of intellectual curiosity, level of responsibility, effort to achieve success, self-discipline and ability to reflect their actions to ensure that students complete their selected career and achieve their personal and professional goals. The diagnosis also includes study skills and habits of the student. For this aspect, they were tested if they organize and plan their time, organize their spaces and places of study, habits of focus, their techniques to take notes, how to prepare for examinations and assessments. Furthermore, among their learning styles diagnosis evaluated whether students have a reflective or active style or both, meaning if they retain and understand best when information is discussed or applied directly or prefer thinking, meditating or previously reflecting; if they are sensorial or intuitive or both, that is, if they learn to solve problems related to reality or whether it is through understanding the conceptual part, liking of abstract theories; if they are more visual or verbal or both; if they are more overall or by sequence or both, as going linearly, by smaller steps following logical steps or displaying the whole picture. UTEC also include activities

<sup>3</sup>Conferencia Anual de Ejecutivos (CADE, Annual Conference of Executives, <http://ipae.pe/cade-ejecutivos/2014>). One of the principal forums organized by the most important executives from the private sector, where they, among other topics, discuss about the education in Peru.

TABLE I  
GRADES OBTAINED BY THE STUDENTS ADMITTED AT UTEC FOR THE SEMESTER 2012-1. THE GRADES ARE IN A RANGE FROM 0 (MINIMUM) TO 20 (MAXIMUM).

Area	$\mu$	$\sigma$	Min.	$Q_1$	Median	$Q_3$	Max.
Verbal	11.78	2.02	6.67	10.67	12.00	13.33	17.33
Arithmetic	14.53	3.62	4.00	12.00	14.67	17.33	20.00
Algebra	16.44	3.48	4.44	13.33	17.78	20.00	20.00
Geometry	14.29	4.53	4.00	10.00	13.33	16.67	20.00

$\mu$ : Average.  $\sigma$ : Standard deviation.  $Q_1$ : First quartile.  $Q_3$ : Third quartile.

and concrete actions based on the diagnostic such as lectures and workshops, coaching and mentoring to help resolving the difficulties identified in this evaluation. One of the objectives is to enhance students' skills that are not yet developed.

In order to reassess every engineering career plan that was offered with the needs of the market and businesses, technical advisory groups were formed (*Comités Técnicos Consultivos* - CTC) for each program and for the direction of management and humanities. For these six CTCs, UTEC invited representatives of enterprises: General Managers, Production Managers or representatives of the public sector who may have more affinity with the careers offered by UTEC. For the Management and Humanities Direction, General Managers and HR Managers of the industry or from the recruitment agencies were invited. Some of the participants expressed their comments about the technical content of each of the courses of the career that were invited, but all of them commented and expressed the importance on the need to acquire soft skills and specific skills of communication, teamwork, creativity, ability to formulate and manage projects, assertiveness, ethical commitment, foreign languages, specially English, among others, all coincide with those defined as generic competences in the Tuning project [19].

This background summaries the current situation not only of Peru in terms of education, but also the regular UTEC plan for all the students: those who are participating in research and those who are not. In the next section, we present the methodology implemented for inviting and training the students to participate in advanced projects in the current research laboratories, and how we have trained them during their participation.

### III. METHODS

In this section, we present the methodology applied to students at UTEC and especially to the students participating in the research labs. We start by describing the curricular plan in subsection III-A. Then, in subsection III-B, we described the formation of the research laboratories based on the experiences and interests of the faculty by the end of 2012. In the last sections III-C, III-D and III-E, we describe the methodology applied to the students since they are invited to be part of the research labs up to the publications of their results in an international conference.

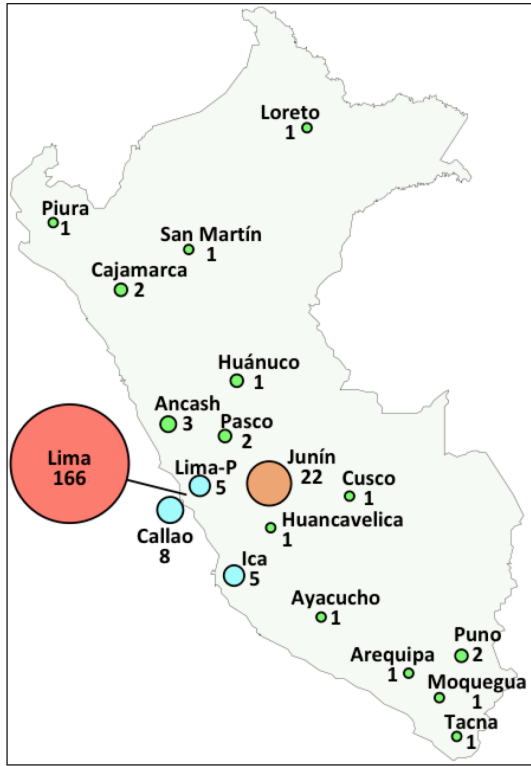


Fig. 1. Map of the cities of the 2012 admitted students at UTEC.

#### A. UTEC Curricular Plan Style

One of the inputs for the form of teaching and learning was corroborated by Professor Kim Vandiver, member of the UTEC Directing Council, Dean for Undergraduate Research of the Massachusetts Institute of Technology (MIT), and Professor Domenico Grasso, from the University of Delaware, both during their visits to Peru for different events. They pointed out the need to create in students the motivation to investigate, proactivity to the pursuit of knowledge, without the waiting that the student has to be in their last years, but since the beginning of their undergraduate studies.

The new course structure in each engineering program offered by UTEC has 25% of Math and sciences courses, 50% of research and engineering courses and 25% of management, humanities, arts and foreign language courses. The art workshops were, for example, oratory and improvisational theater workshops, which are mandatory for students. These courses have been happily received because they teach specific techniques to exhibit their work, stage domain, and others. Other complementary activities necessary for the first year of study at our university, that has a high creativity component, were to have professors trained with specific technical knowledge of the courses but also with the knowledge about how to apply different forms of active learning, as well as techniques of individual students, for which they were trained in mentoring issues.

For the Management, Arts and Humanities courses, UTEC

have signed alliances with Universidad del Pacífico, which is well known for their expertise in management and economic themes, the Universidad Antonio Ruiz de Montoya, specialist in courses related to humanities, and the Museum of Contemporary Art for art workshops. Students go to these institutions and take the previously selected courses that are part of the new curricular plan. In this type of experience, students learn different types of education, they also alternate with many other students that are not in engineering programs, in a different environment, customized, among other factors, for enriching their college experience starting in the first semester. All of this big change would not be possible if the organization and senior management of the institution did not support the initiatives proposed with great flexibility, dynamism and proactivity.

#### B. Definition of the Research Labs

UTEC is constantly looking for young professors, with a Ph.D. degree, and with international experience in research and development (R&D). Even if this is common in developed countries, that is not the case for developing countries like Peru. In these countries, most of the professors are good local professionals, not always bilingual, and with almost null experience in research or publications. The needs of Peru make the professionals to be focused more in development of projects rather than research. In terms of the degrees, after finishing the undergrad courses in Peru, the student becomes a Bachelor of Science (B.S.). This diploma is not enough to work in Peru since you need to defend an undergrad thesis to get an 'Engineer' diploma.

This current limitation of not having high standards for faculty in Peru is related to the fact that Peru was, until 2002, the country with the lowest number of scientific publications in the region (see Table II). Even if the reasons are related to the low investment of the universities in R&D (only 3%) and the almost no participation of Peruvian universities in R&D projects funded by international agencies [20] (for example NSF, NIH, EU, etc.), one of the main reasons is the low experience of the professors in R&D.

By the end of 2012, UTEC faculty was from different areas, experiences and degrees. Among faculty, 46% of them had a Ph.D. degree. Four of them returned to Peru within the last year with different backgrounds. To begin with the creation of the research labs, all faculty was interviewed about their research interests (with or without experience). Since UTEC started its first classes in 2012, and the research interests were diverse, we clustered the topics to create four research labs. An experienced Ph.D. professor would lead each lab with focus on topics of current worldwide research with applications in Peru.

The research labs created were:

- 1) Information Technology (IT): This group is led by a Ph.D. in Electrical Engineering, expert in Digital Image and Video processing, with high experience in recon-figurible hardware design. The topics covered here are: (i) digital image processing, (ii) computer vision, (iii)

TABLE II  
ABSOLUTE SCIENTIFIC PRODUCTION BY NUMBER OF PUBLICATIONS BY  
COUNTRY (SOURCE: SCIENCE CITATION INDEX).

Year	Brazil	Chile	Colombia	Mexico	Peru	Venezuela
1993	4,827	1,363	219	3,714	160	732
1994	5,253	1,330	280	4,041	141	700
1995	6,526	1,587	349	4,556	172	733
1996	7,255	1,677	434	5,123	185	844
1997	8,530	1,754	517	5,605	171	952
1998	10,185	1,814	542	6,008	203	1,057
1999	11,665	2,062	610	6,792	180	1,077
2000	12,317	2,258	701	6,873	234	1,112
2001	12,798	2,375	752	7,386	295	1,176
2002	14,999	2,564	776	7,533	310	1,107

FPGAs, (iv) Mobile Apps, (v) Parallel computing in CUDA, and (vi) Cloud computing.

- 2) Energy Systems and Nanotechnology: This group is led by a Ph.D. in Electrical Engineering, expert in MEMS, nanotechnology, material science, RF engineering and superconductivity. The topics covered here are: (i) Energy harvesting, (ii) Power electronics, (iii) smart grids, (iv) renewable energy, (v) microelectronics, and (vi) nanotechnology.
- 3) Optomechatronics: a Ph.D. in Mechanical Engineering, expert in micro-robotics, leads this group. The topics covered here are: (i) sensor and actuators, (ii) simulations, (iii) mechanics, (iv) electronics, (v) informatics, (vi) signal processing and (vii) optics.
- 4) Materials Science and Engineering: a Ph.D. in Chemical Engineering, expert in nanomaterials, leads this group. The topics covered here are: (i) solar cells, (ii) catalysis, (iii) coatings, (iv) water filters, (v) sensors and (vi) actuators.

Nowadays, UTEC has more research labs and groups, but most of them are for developing advanced projects with Peruvian industry companies. The original research labs are still working with new students every year.

### C. Invitation to freshman students

By the end of 2012, when the first freshman students were finishing their first year, Ph.D. professors invited all the students to show the available research areas. The presentation was an 1-hour talk in the last week of classes in December 2012. By the beginning of January 2013, each group started with about 16 students, from different engineering programs. The students that did not participated in the research labs still had the opportunity to learn about research and development projects during their mandatory, and graded, semester projects. However, the training and difficulty of the projects in the research labs were higher.

The students started working with the research labs by the third week of January 2013. The methodology applied with the students was project-based learning (PBL) as:

- 1) In the first meeting, the professors participating in each research lab explained all the topics to be covered in

the research labs. The PBL methodology to be used was also explained: each student would be assigned to develop a fun project. They would be guided about how to find the information, how to use it, and how to test it. Examples of projects were presented to the students, but also the students had the option to present their own project proposals in the next meeting. We called this assignment as: tell us what you want to do.

- 2) In the second meeting, the projects and topics proposed by the students were discussed and tuned. Students chose their projects to start the learning process to develop the project. Example of these projects were: (i) implementation of a calculator (or a small arithmetic logic unit -ALU) implemented in a FPGA using VHDL, (ii) implementation of a single Facebook application using Python and the Google App Engine, or (iii) implementation of a calculator for iOS.
- 3) In the next weeks, the official group meetings were once a week. If a student had doubts about some topics, they used to go to ask the professors. Some of the students spent full days (semester '0' in Peru is Summer) working on their projects. Their progress evaluation was assessed in three parts: (i) related to their progress to reach their goals in the proposed time, (ii) a 4-page paper presentation, and (iii) asking them questions to evaluate if they have learned or they are only copying the information available on the internet or in books. The students were able to use any tools like books, internet, forums, etc. with the only condition of writing the right reference for their work. It is important to recall that the students finished only their first year of studies, with most courses related to basic science and not engineering courses yet.
- 4) By the end of the Summer semester (first weeks of March 2013), not only their projects were evaluated but also the level of knowledge acquired and their skills for self-directed learning. In the case of the IT research lab, from 16 students starting the projects, only 5 were able to produce results close enough to their goals. Those students were invited to keep being part of the IT research lab.

In the specific case of the two students implementing reconfigurable hardware design, they learned the basics of digital circuits (the course is taught in the fifth semester) and how to implement basic hardware systems using VHDL. Thus, these students start becoming hardware implementers, something similar to programmers.

### D. Progress of the students during the regular semesters

During the regular semester, all UTEC students must develop a semester project. This project is similar to the Capstone projects in the USA but defined for each academic semester. This is mandatory to all students and they have to finish at least eight projects during their studies to finish their engineering program. The project must be supervised by a

faculty member and can be developed with a maximum of 4-5 students per group. Professors invite students to present their progress during the semester at least three times: presentation of objectives, progress of the project and final results. For the case of the students participating in the research labs, their new assignment became their graded semester project with the same rules: if they pass the project, they will receive one project credit.

For the case of the two students working with FPGAs and VHDL, since they needed to keep learning the basics of those topics, their 2013-1 project was to implement an arcade game (similar to Galaxian by Namco from 1979). The system should be implemented 100% in hardware, i.e. sequential processes implemented by software were not allowed. The project included controlling a VGA monitor, to control the I/Os of the FPGAs, to use the internal memories, and to adapt the game to something more local. The students successfully implemented the game by the end of the semester. Note that there are similar projects on the web and the students were allowed to use that information. However, they were assessed based on their knowledge acquired and the development of the project.

For the next semester 2013-2, we were looking for projects to keep applying PBL for their learning. One of the objectives in choosing the project was that this should work as the beginning for a high level research and development project, something that within that year could be published in an international conference. Thus, because of collaborative work of the leader professor of the IT research lab with the Air Force Research Labs (AFRL, [21], [22], [23], [24]), Kirtland, United States of America, a topic was chosen.

The topic was related to a current challenge for satellite communications. The idea was to implement a universal link that could handle multiple low-voltage differential signaling (LVDS) connections using only one LVDS link. Thus, the hardware should be able to multiplex and demultiplex the signals such that each individual connection does not suffer any change. This challenge appears from the fact that LVDS requires two wires for a simplex communication and four wires for a full-duplex one. Thus, for a single communication the number of wires is increased by three compared to other communications. Even if the cost per pair of wires is still low, for a big network this becomes a problem.

Since the full project requires many hours of research with experienced professionals, the project was limited to a proof of concept. The goal was to implement a first approach to the system to prove if that can be implemented or not.

The students were advised by the leader professor, who also participated in the project with the implementation of the advanced parts of the systems. Also, a researcher from AFRL was constantly giving feedback about the progress and the results. Since the results were good enough for a first approach, we proposed the students to improve their writing skills by writing a paper to be submitted to an international conference in microelectronics.

## E. Publication of Results

To meet the call for proposals for the IBERCHIP 2014<sup>4</sup>, the students had to finish their project before the end of the semester 2013-2. This semester ends by the second week of December, but to the project and the paper was required to be ready by the middle of November. There were no big problems in terms of the results, but one challenge was the writing of the paper.

Even if the students were guided about how to write a paper during the summer semester (2013-0), their writing level was not good enough. Thus, the students were guided about the paper writing for a technical conference [25].

The paper writing learning was like:

- 1) The students were asked to write the introduction and background in Spanish (native language). They were asked to write one page per section in a double column format. The objective was related to teach them how to write all their ideas and information, and to remove unnecessary information.
- 2) Then, the students wrote about the methods and results. This part took more time since it was found that the students repeated the information many times. Also, for the results, they did not know how to produce the correct figures and tables to make their paper easy to understand.
- 3) Next, the students wrote about the discussion of their results, conclusions, and future work. During all the process the students were writing the bibliography in the right format.
- 4) Finally, the students changed their Spanish version paper into an English version. They learned to do not literally translate from Spanish to English, but to think in English, to write the correct expression to explain their ideas.

The professor of the IT research lab revised their final version twice. Later, the researcher from AFRL revised the paper. Finally, the students submitted the paper [12] by the end of November 2013, and it was accepted for oral presentation in the IBERCHIP 2014 conference held in Santiago, Chile, in February 2014.

The students prepared their presentation, in English, during January 2014. Then, they were asked to present their version of the presentation to the professor. The goal was to adapt their presentation to a good format for an oral presentation. The students repeated the presentation about 8 times (twice per week) until they had at least a middle quality presentation. After that, the students made a presentation to the UTEC Research Director, and to UTEC faculty. A lot of feedback was received until a high quality presentation was developed. Also, we discussed about possible questions that could be asked during the final presentation, from technical questions to non-technical ones.

The students presented the paper in a 15-minute presentation, in English, in a session with grad students and professors.

<sup>4</sup>IBERCHIP 2014 call for proposals: <http://www.ieee-lascas.org/lascas2014/iberchip/call>

The preparation of the students in terms of tuning the presentation produced good results. The presentation was performed with high quality and the questions received were answered in a correct form.

#### IV. RESULTS AND DISCUSSION

In this section, we present the results in terms of the technical knowledge acquired by the students that have participated in the research laboratories, the soft skills developed during the process, their performance in classes after their first year of participation in the research labs, and their current research development.

##### A. After classes technical knowledge learning

In terms of technical knowledge, the students learned different basic and advanced topics on digital circuits design. We can summarize their learning as:

- Two months during 2013-0: Basic concepts about VHDL implementation of basic arithmetic and logic functions, and implementation of the system in a FPGA. The students started learning these topics from scratch without any digital circuits or hardware implementation course, only using PBL. Also, they learned about how to make test benches in VHDL and writing basic papers to describe their work (in Spanish).
- Four months during 2013-1: Basic concepts about implementation and interconnection of modules and hardware blocks in VHDL, concepts about IP cores, memory blocks, and I/Os in FPGAs. Also, they learned about different syntheses for area and speed optimization.
- Five months during the winter break and 2013-2: Advanced implementation of modules as part of a large system. Oriented implementation of test benches under different possible situations. Also, the students learned about how to search for papers related to their work and, more important, how to read and use them.
- Two months during the last part of 2013-2 (this started during the implementation): Writing of advanced documentation in a paper format for an international conference (in English).
- First months of 2014-0: Preparation of technical presentations for the conference (in English).

By the end of this process, the students had knowledge of intermediate topics on digital circuits. The students are taking the course "Digital Circuits" in 2014-1, after the presentation of the conference. Their performance is better than the rest of the class. Also, during the class, they ask questions about how to use the topics learned for further systems, instead of the typical questions about, for example, doubts about the topic of the class.

##### B. Soft skills developed

The students have proven that the fact to participate in advanced research projects starting at the first year led them to improve their skills to achieve a much more comprehensive view of how to analyze the problems. It has helped students to

be more creative, in information seeking, approach problems and solutions, and not been limited to copy available information, creating virtuous circles between professors, students, university community and society in general that benefits from the development of these research projects.

They have found great motivation in further research, to provide and search not only for problems of the repeated textbook information, often not suited to local realities but also for solutions to real problems. Also, after their first research experience, they have defined their future specialty and vocational guidance. This have been even published in the local news where one of these students wrote a small article about undergrad research [26].

Also, UTEC created the Academic Personalized Advisory and Support Centers (*Centros de Asesoría Personalizada y Soporte Académico - CAPS*), where these students with research experience, desired skills and better performances in classes, are able to help other students to learn the topics that they have problems or they are not getting the desired results.

These two students have developed leadership skills, group management, teamwork, and responsibility and, also, strengthen their learning and teaching skills and research. Furthermore, these students feel that they have improved in their academic achievement, in the quality of interpersonal interactions, self-esteem, perceptions of greater social support, their student attitudes [27]. Also, they act independently, assume responsibility, face challenges, enjoy their achievements, tolerate frustrations, influences other students, feeling competent capable and valuable and also are able to express themselves in Spanish and English without timidity, with a good tone of voice, good body position, among others.

##### C. Performance in classes

According to interviews to the two students participating in this undergrad research methodology, they think that these experiences have helped them in how to approach the problems and objectives, have a working methodology with a research process and make conclusions and recommendations. This methodology is applicable to the courses that they are studying and the courses in which they are participating as coaches to their peers in the CAPS. Something very important is that these young students know that they have to try to get the most out of each course because they know that in the future the learned topics will serve as the basis or input for more advanced courses.

The students have developed research and self-education skills. When they have concerns in class, they research about it, so, if possible, they bring something extra to the problems of the class. They also commented that this requires a lot of extra work and do not always have the desired time to research, but the support of mentors and teachers helps with the challenge.

They have noted the importance that the professor is a great motivator to continue active learning methodology. These students have respect for, and understand the necessity and function, of the professors [28]. They understand that their

professors can drive groups of students and teach them to understand and achieve the final goal.

In terms of their performance in their classes, they have improved their learning in classes since they are trying to adapt this methodology to their regular courses. Even if sometimes the grades do not represent if the students are learning or not, it is important to mention that their grades are higher than the average class, even with the new and more difficult courses that they are currently taking.

#### D. Current research skills

In terms of research skills, we can start with the skills related to the search of information. The students improved their skills for searching information on the web, especially in Google Scholar. The students now search, read and use papers to keep working in their projects. A result that exceeds expectations is that the students not only read the papers, but also, they can select the parts of them than can be used, or they can often select when a paper can be used or not based on the understanding of the abstract, discussion and conclusions.

In terms of their progress in current projects, the students need less orientation from the professor. They meet the professor for a mandatory weekly meeting, but also, they request extra meetings when they need them, but the meeting is to solve specific problems only. The students have learnt that when they are stuck in some part, they need to try to solve it by keep trying new alternatives for the solution and to search for available information. However, if they are stuck for a long time, they request an extra meeting where they present the problem, their alternatives to solve it, and we look for a solution as a team. To improve the solution of the project, equipment from the university (FPGA boards) have been assigned to them so they can try their solutions at home.

We have seen many advantages in the use of this methodology; the students have started developing skills that are usually developed during the undergrad thesis or in grad school. Also, the students are developing the skill of self-education to learn topics that interest for them, many of them could be taught in the regular curricular plan. In the other side of the picture, there are also challenges related to improve the number of students who can keep up with research, in addition to their core courses currently enrolled. Due to the weaknesses of knowledge of some of the students (different background, different high schools), to catch up with colleagues who have better skills and competencies make this methodology a big effort, not everyone can finish the projects that are not related to their courses. In terms of the professors leading the research labs with these young students, their thoughts are related to the performance of the students. On one hand, if they succeed, the professor think that the experience is great (young trained students to work on high level projects). On the other hand, when the students are not hard workers or they abandon the research lab, their thoughts are related with the high demand of time required to train non-skilled students and get no benefits, neither a finished research nor a trained student.

One important aspect to keep in mind is that students are motivated and continue to do research as a form of learning. The professor is the agent who guides the student. This professor must know not only the technical knowledge in their field, but also in PBL. Thus, the university must support them with time and resources that can be devoted to research with their students. To promote research as a form of active student learning, the organization must have a comprehensive strategy. It is not enough to know the techniques of PBL, it has to be accompanied by other courses to improve the skills of students as expressed correctly in both oral and written, to speak other languages, to do effective presentations, to have security, to trust himself, control of the circumstances, among others, named soft skills throughout this paper.

#### V. CONCLUSIONS AND FUTURE WORK

We have presented the case of two students who were part of the new methodology to invite undergrad students to be part of advanced research laboratories since the freshman year. The first results show: (i) the importance of working with undergraduate students based on a PBL methodology to achieve better results and to decrease the number of dropouts, (ii) the soft skills required by the professionals can be worked from the freshman year and not wait until they are studying at graduate school, (iii) the fact that science and knowledge are always changing makes the students who are capable of self-education and with a constant training of soft skills stand over other students. As a future work, we plan to increase the number of research laboratories. Currently, we have increase the number of students who participate in different advanced research projects in the research laboratories.

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