Project (and Problem) Based Learning in Engineering Education: The Fab Lab UTEC Experience

Isaac Robles

Isaac Robles, Universidad de Ingeniería y Tecnología-UTEC, Lima, Peru

Abstract

For the Last 18 Months, the Fab Lab UTEC has been, as part of the larger Educational strategy of the University, developing a structure of workshops, courses and experiences based upon Problem and Project-Based Learning as part of its role in the Education Process for the UTEC University students in Lima, Peru. The Paper discusses the initiatives deployed, its definite characteristics and results up to date, the intended approach for each initiative and the results obtained after three semesters of application of the program. Further analysis that can be applied or translated to other domains is finally discussed.

Keywords

Problem-based learning, Project-Based Learning, Education, Engineering, Fab Lab, 3D Printing, Program Design, Prototyping, Integration

Project (and Problem) Based Learning in Engineering Education: The Fab Lab UTEC Experience

Isaac Robles

Isaac Robles, Universidad de Ingeniería y Tecnología-UTEC
Lima, Peru
irobles@utec.edu.pe

Abstract

For the Last 18 Months, the Fab Lab UTEC has been, as part of the larger Educational strategy of the University, developing a structure of workshops, courses and experiences based upon Problem and Project-Based Learning as part of its role in the Education Process for the UTEC University students in Lima, Peru.

The Paper discusses the initiatives deployed, its definite characteristics and results up to date, the intended approach for each initiative and the results obtained after three semesters of application of the program.

Further analysis that can be applied or translated to other domains is finally discussed.

Keywords

Problem-based learning, Project-Based Learning, Education, Engineering, Fab Lab, 3D Printing, Program Design, Prototyping, Integration.

1 Introduction

The present paper is a summary on the experience and findings based upon the work undertaken for Fab Lab UTEC in collaboration with the Industrial Engineering Department in UTEC University during the last 18 months. First, an historical background and context part describes the Evolution of the Fab lab Network in Peru and in particular, the Fab Lab UTEC Evolutionary process.

Second, a narrative of the Interventions of Fab Lab UTEC in the Engineering Students formation is described, including the initiatives undertaken and its results.

Finally, an analysis and discussion of the results and perspectives towards future developments is discussed.

2 Historical Background

The origins and history of Fab Lab UTEC are directly intertwined with the evolution of the Fab lab Network, globally, and the Peruvian Fab Lab community in Particular.

The informal birth of such community starts in 2009 with the selection process for the AECID Grant awarded to the Peruvian Government for the first Fab Lab Set-up, which led to the selection of the first two Fab Academy participants (Fabbers) who would attend The Fab Academy Course in Fab Lab Barcelona, the two selected (Beno Juárez and Victor Freundt) and the non-selected (plus some additional interested) established an informal community to support this effort. This would be the seeds of what would become the Fab Lab Peru Association and the Latin American Fab Lat Network.

The next landmark in this evolutionary process was the establishment and opening of the First Fab Lab in Peru, via the AECID grant, in the Faculty of Architecture in the National Engineering University (FAUA-UNI) at the FAB7 event in Lima, Peru in August 2011.

In Peru, the evolution of the Local Fab Lab Network has seen a greater participation from higher learning institutions instead of grassroots communities, to date; the majority of established Fab Labs are set in higher Learning institutions, the timeline for their evolution being as follows, according to the fablabs.io database to date:

- Fab lab UNI (Lima), 2011
- Fab lab Museo Metropolitano-MUME (Lima), 2013 – 2015
- Fab Lab TECSUP (Lima) , 2013
- Fab Lab ESAN (Lima), 2014
- Fab Lab UTEC (Lima), 2015
- Lima Makers (Lima), 2015
- Fab Experience Café(Lima), 2016
- Fab Lab USMP(Lima), 2017

As it is noticed, the expansion of the Fab Lab Network has mostly been due to the Efforts of Private Educational Institutions rather than grassroots or civil society initiatives. This due to the natural entry barrier set by the investment needed for the standard equipment, and, arguably, to the value perceived by such institutions on how a Fab Lab can improve their educational offering.

Fab Lab UTEC was established as part of the New UTEC University Campus Building in the second half of 2015 and by initiative of the Industrial Engineering Department envisioned as a technological support space for the courses and Projects in the Academic Curriculum.

The Fab Lab interventions in this process are the following:

1. Proposing and managing projects for the Interdisciplinary Projects Workshop.
2. Collaborating with Professors developing lab experiences for the students.
3. Offering informal instruction on Digital Fabrication.

3 Digital Fabrication Interventions in UTEC University

3.1 Collaboration on Regular Courses

3.1.1 Notes on Class Design

The laboratory sessions provided by the Fab Lab are co-created with the Course Professor(s), in regards to this, we try to work under an active learning methodology which can be summarized in the *Teaching Canvas*, a canvas derived from the *Product Archaeology Canvas* (Tranquillo, 2015), displayed in the figure 1 below:

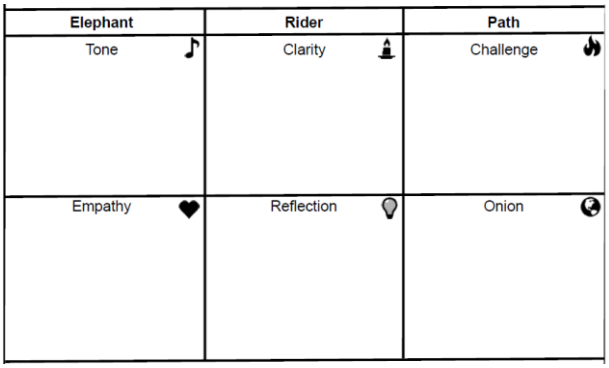

Figure 1: Teaching Canvas

The canvas is a useful method to setup the class in an integral manner, letting us comprehensively blend and organize the contents, timing and set up for the class. It is composed by three columns which are about the emotions and motivation (*Elephant*), Rationality and Reflection (*Rider*) and Content and implications (*Path*). This sets up the class in the Framework of Problem-based Learning.

A demonstration for the Teaching Canvas regarding one of the classes we set up will be shown in the next section.

3.1.2 Cases of note

The Fab Lab occasionally hosts Laboratory Sessions for Regular Courses, in particular, the Course of Products and Services Design (fifth semester) in which and Induction for the Fab lab, the technologies used and their implications are shown and discussed. This is done in two sessions:

In the first, the students get receive and introduction to CAD and their assignment is to reproduce a blueprint in Solidworks in the class, for this, the lab instructors provide a flipped Classroom Instructional video that is worked upon and reinforced in class. A screen Capture of the flipped classroom video can be found in Figure 1 below:

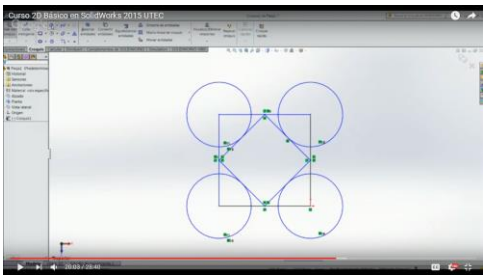

Figure 1: Flipped Classroom video for Solidworks

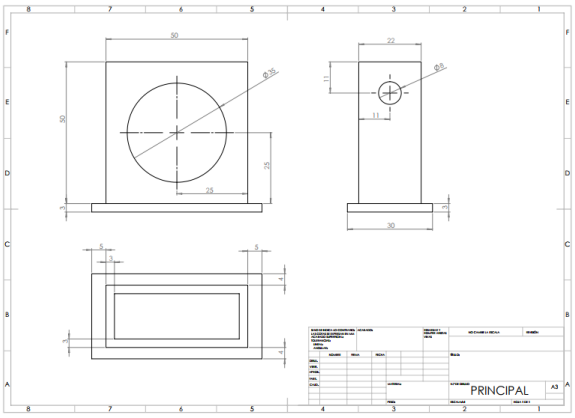

Figure 2: Blueprint of the piece to be designed in Solidworks

The designed Pieces will be sent to the Fab Lab in order to be 3D printed, in this, we show the students how to prepare the prints and make an estimate of the necessary time and material for printing the set pieces, as it can be seen in figure 3:

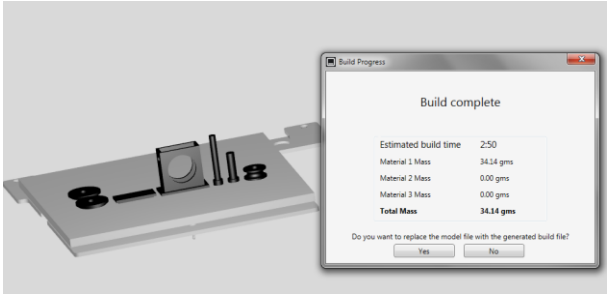

Figure 3: Preparation for 3D Printing using CubePro Software.

Afterwards, after the printing is finished, the students compare the dimension of the blueprints to the prints in order to determine how precise the printers are and if the assembly can be made within the designed tolerances.

Afterwards, they would analyse the results in order to state how reliable the Printers may be, noticing how from the same 3D Printer different results can be obtained.

Another experience designed for this course was regarding low-resolution prototyping, the class assignment for the students was to replicate the form of a common use device using cardboard, plasticine and other office supplies, from there, improvements to the perceived design were to be proposed for the next class, a few examples can be seen in figure 4, below:

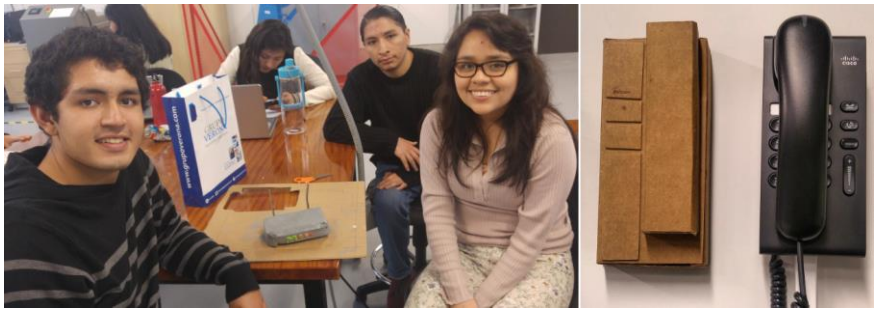

Figure 4: a group of students and a model of a wireless router (left), the cardboard model of an intercommunicator(right) – from the Product design workshop

In order to set up the class, we used the Teaching Canvas shown in the previous section; the considerations Taken into planning the class in each aspect are shown in Table 1:

Elephant	**Rider**	**Path**
Tone	***Clarity***	***Challenge***
- Form Groups via Random Selection. - Hook Statement: Device prototyping and e-waste	- By the end of the class the students will complete a low-res prototype of a common-use device	- Each Group will work creating a low-res prototype of a common-use device. - After time-limit, a gallery walk will be done, where peers and the instructor give feedback to the group.
Empathy	***Reflection***	***Onion***
- How can we demonstrate how the prototyping process can create an impact for all stakeholders?	- How can the prototype you created be improved? - Can you estimate which steps would be needed to implement such improvements?	- Which materials would be needed for a real product? - Where would they come From? - Where is the real added value? -How does this contribute to the e-waste problem?

Table 1: Teaching Canvas for Product Design Workshop Session (English Translation by the author)

In both cases, work was assessed via direct feedback by the instructor and by self-assessment at the end of class via a rubric, described in Table 2:

Assessment Rubric: Low Resolution Prototyping	
Please Rate From 1 to 5 (being 1 "I do not understand this topic" and 5 being "I completely understand this topic") about the following:	
I know what a low- resolution prototype is.	
I can distinguish a low-resolution prototype from a high-resolution one and a production sample.	
I can assess which kind of prototype is needed for a certain user during the development phase.	
I can ask for feedback about the prototype of my product regarding the stage I am working at.	
I am able to analyse and propose improvements for the prototype.	

Table 2: Assessment Rubric for low-resolution Prototyping Lab Class (English Translation by the author)

3.2 Interdisciplinary Projects workshops

3.2.1 General Characteristics

The interdisciplinary Projects Workshops (AKA VLI) are mandatory workshops that students in UTEC University take between the third and seventh semesters over the ten semesters of Instruction. The Workshop dynamics are based upon Project Based Learning. Depending of the Program, a certain student can take between two and four instalments of the Workshop.

The dynamics and organization for the workshops have changed during the last three semesters; however the main characteristics are:

- ***Project Proposal Ideas:*** They can be submitted into consideration by a student (or group of students), Faculty, a Lab or a Company (Provided there is an agreement between the company and UTEC).
- ***Sponsors and Advisors:*** The interested parties need to find a sponsor for administrative and budgetary reasons, these sponsors can be an Academic Department or a Company, also, every project needs at least one Faculty advisor to aid and assess the students during project Development.
- ***Costing and Budget:*** Each project has a budget granted by the sponsors, with a minimum of 500 PEN (about 155 USD) in materials, this amount can be higher depending on the complexity of the project and does not take into account indirect costs such as machines use time and advisory time.
- ***Freedom of enrolment:*** Any student taking the workshop is free to enrol in any project regardless of which Department sponsors or whatever major the student is pursuing, this leads to multidisciplinary teams and approaches.
- ***Continuous Assessment and Feedback:*** The advisor responsibility lies in keeping constant contact and offer continuous feedback and assessment during the project, sometimes, as it will be discussed later, this implies engaging in informal instruction efforts (i. e. Tutorials, Seminars) in order to better aid the students.
- ***Assessment based upon learning and results:*** The assessment for the teams is two-fold: the project results are assessed via a time schedule that the students propose at the beginning of the semester in agreement with their advisor(s) with certain landmark achievements to be made on a certain time frame for the project to be complete, however, this is rarely the norm, so the adjustments made for time or budgetary constraints also factor into the assessment process.

TIMELINE/CRONOGRAMA/MILESTONES	WHEN	WHAT	WHO
	Semana 2	Informe sobre impresoras 3D	Isaac
	Semana 2	Aplicaciones de impresión 3D a alimentos	Todos
	Semana 4	Concepto de diseño de la máquina	Todos
	Semana 5	Diseño del prototipo	Todos
	Semana 5	Elementos de Construcción	Todos
	Semana 6	Lista de Compras	Isaac
	Semana 7-9	Compra de suministros	Isaac
	Semana 9-11	Desarrollo del Prototipo	Todos
	Semanas 11-13	Pruebas del Prototipo	todos
RECURSOS	Uso de máquinas del Fab Lab Conocimiento de Diseño Presupuesto de compras		

Figure 5: Project charter for a Fab Lab sponsored VLI Project (screencapture by the author)

The second part of the assessment is the learning process. This is more qualitative and has to do with how effectively the students have grasped the necessary organizational and technical skills to bring the project to fruition.

3.2.2 Fab Lab interventions and contributions to the Workshop

During the last three semesters, the Fab Lab has been proposing, sponsoring and supporting projects for this workshop; a few of note are shown in Table 3:

2016 – I Projects	**2016 – II Projects**	**2017 – I Projects**
Design of an exoskeleton for reducing workload of docker personnel	Design of an interface for a Martian Climate Simulator	Design of a Plastic Recycling Device
Design and Prototyping for a Transtibial Prosthetic	Design and Prototyping of a Plotter Machine to Fabricate PCBs	Design and Prototyping of a Plotter Machine to Fabricate PCBs (continued)
Design and Prototyping for a Glass window cleaner Robot	Improvement of a Delta Mechanism for clay 3D Printing	Design and prototyping of a Food Printer
Design of a Plastic Injection machine	Designed of a Radio Controlled Robot with a caterpillar transmission	Design of an automated mobility attachment for conventional wheelchairs
Design and Prototyping of a Thermoforming Machine		Design and Prototyping of a Thermoforming Machine (continued)
Fabrication for a mid-resolution Robotic Arm		

Table 3: VLI Workshop Projects proposed by semester from the Fab Lab.

As it can be seen, the Projects proposed are mostly about design and prototyping of devices which brings different issued that are address using Project-based Learning (Larmer et al, 2015):

- ***Key Knowledge, Understanding, and Success Skills:*** In order to achieve a relevant result in the project proposed, individual and team learning need to be enabled, it is also important to balance theoretical instruction (Seminars, Tutorials) with hands-on experience. The scope of these projects becomes too wide for a single student to master all of it; therefore, team organization and communication become key issues. Making the students internalize the concepts of Spiral Development (what do I need to do in this iteration?) and Integration (The sum of the parts is

more than the individual components/systems) is also highly stressed during advisory sessions. One advisory session with several working groups is shown in Figure 6 below:

Figure 6: Advisory Projects Session

- ***Challenging Problem or Question:*** Depending of the Project, a real-world related problematic is touched, ranging from plastic waste pollution (plastic recycling) to food waste (food 3D Printing).
- ***Sustained Inquiry:*** The approach towards the project development is composed of stages of questioning, the Team needs to research, choose what to do and adapt when expected conditions are not met (i. e. parts sourcing).
- ***Authenticity:*** The project must be done with local sourced materials, which sometimes leads the students to peruse second-hand markets and recycled/repurposed parts/devices.
- ***Student Voice & Choice:*** The students co-create the project with the advisor, and have the liberty to propose changes in scope, deadlines and strategy, in a constant feedback loop.
- ***Reflection:*** During advisory meetings, spaces for reflection are provided, in order for the team to better assess project status and challenges ahead.
- ***Critique & Revision:*** the advisory meetings are also a place for revision, feedback and critique. The advisor works with the students in order to clarify any issues regarding technical expertise or project development, sometimes setting up Tutorial sessions for technical training (more on this on the next section)
- ***Public Product:*** The final step in the workshop Process is The Projects Fair. In order to qualify for the Fair, the students need to prepare a poster explaining the Project Development and results, after which the best two projects for each engineering Program are selected to present in the Fair[1]. A poster example is displayed in Figure 7 below, Figure 8 shows a project in display in the fair.

Figure 6: Project Poster

[1] For reference, a press reléase for the Projects Fair in 2016-I Semester, see: https://www.utec.edu.pe/noticias/mas-de-50-proyectos-innovadores-en-la-feria-vivir-la-ingenieria-de-utec

Figure 8: VLI Project Fair.

3.3 Informal Instruction on Digital Fabrication (Nano Degree)

During the Project work, we found out that there was a very definite need to train the students in the use of Digital Fabrication tools in order for them to implement this knowledge into their projects.

Initailly, this led to organizing informal seminars or Tutorials with the groups, in figure 9 below, a training session in Solid Works is shown:

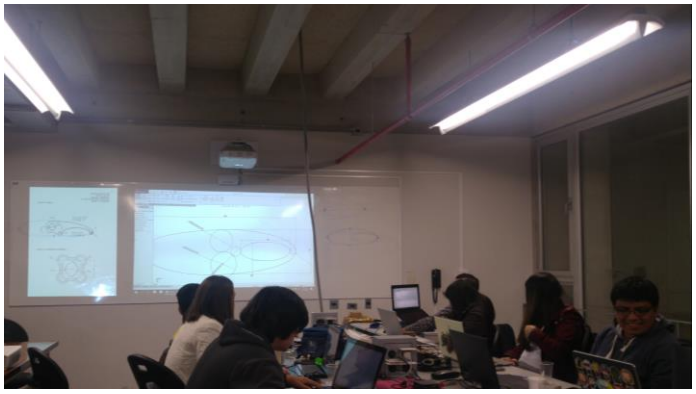

Figure 9: Solidworks training Session.

However, as the number and complexity of Projects increased, the strategy of setting training sessions on a loose schedule was proven too limited, so, during the 2016-II semester a new Training Program was designed. Its aim was to train the students in the essentials of digital Fabrication in order to help them go through the required learning curve for the Projects enrolled. The first approximation to an integral program was presented in November 2016, with distinct levels and achievement badges (or patches) for each (see figure 10 below)

Figure 10: First informal course Organization, presented on November 2016

The original concept was to select a small group of students in order to train them to be “power users” and aid other students project, but, as the following months went by, it was realized that the potential demand was higher than expected so, instead of making a single cohort go through all the levels, a more on-demand enrolment system was implemented, thus the students will only enroll in the training

sessions that they need, completing the levels (and badges) in other semesters as they see fit. The Program was named *Nano Degree* and started deploying in March 2017. In figure 11, a schedule for the sessions can be shown:

Figure 11: Nano Degree Program schedule for April-May 2017

The schedule was set up so any student could have at least two opportunities to take a session.

In some cases, the more advanced students took charge of teaching some sessions, as it can be seen in Figure 12:

Figure 12: Nano Degree Laser session.

Since there was a loose enrolment policy, we could not establish prerequisites for any session, so the background of the participants was varied. The enrolment totals are shown in Table 4 below:

Enrollment and attendance Nano Degree Program 2017 – I Semester	
Total enrolled	475
Waiting list enrolled	180
Effective attendance	140
Attendants/enrolled	**29,47%**

Table 4: Enrollment and attendance in the Nano Degree Program.

About the students' participation, the majority of them came from Industrial Engineering (69 attendants) followed by Mechanical Engineering (47), and Mechatronics and Energy Engineering (6 and 9 attendants) This probably due to the way the information about the program was spread.

After the first semester, the Program has 9 graduates: 1 in level I, 5 in level II and 3 in Level III as well as 7 honorable mentions (students just one session short of completing a level).

After the semester ended, the instructors met to assess the results and improvements to be made for the program. The results will be discussed in the following sections.

4 Results of these interventions

After the implementation of these initiatives, we have obtained the following results:

- ***More engaging Classes:*** As per qualitative references, the students who engaged in Fab Lab Activities as part of their coursework have shown high levels of satisfaction, according to the Course Professors.
- ***Community formation and bonding****:* Students who have worked in a Project with the Fab Lab are likely to return to the Fab Lab for further workshops or as a collaborator in other projects during the off-seasons. A case of note is the development of a large-format clay 3D printer developed during the austral summer, in the off-season, getting close to a functional prototype (see figure 13)

Figure 13: large format clay 3D printer developed during the summer.

These projects also are displayed in University events, giving their creators motivation and feedback about how real-world applications and potential (Figure 14)

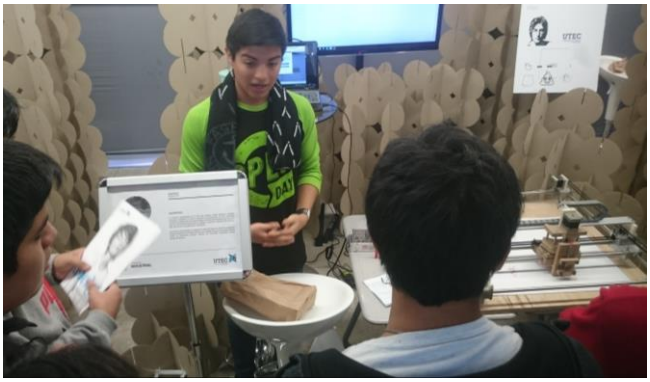

Figure 14: Project on display in a University Event.

An informal community arises this way and grows as more engaged students bring their friends to the lab and enroll them in the lab activities, acting as de-facto lab assistants.

- ***Empowerment towards project-oriented work:*** The students engaging in Fab lab Activities are likely to keep working on Projects in or outside the lab.
- ***Complimentary Formation:*** The students attending Nano Degree sessions show high levels of satisfaction with the lessons received, according to an anonymous poll sent to them. In this, most of the respondents qualified the lessons of the Program as “satisfactory” and “relevant to their project work” as it can be seen in Figures 15 and 16.

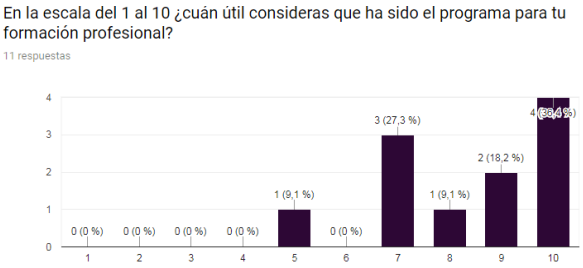

Figure 15: Satisfaction levels with the Nano Degree Program (1 lowest - 10 highest)

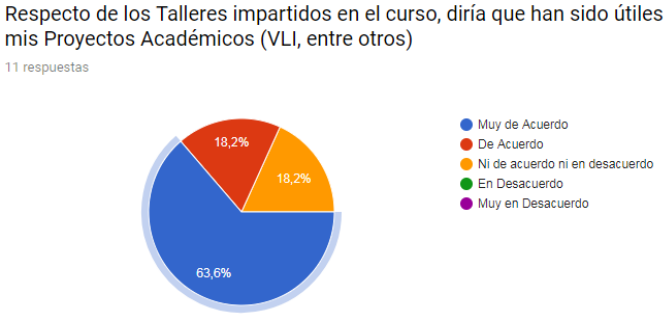

Figure 16: Relevance of the Nano Degree lessons regarding Students' Projects

- ***Blind Spots:*** However, the implementation of these initiatives has also made patent the need for improvement.
  - *On Course Lessons:* More collaborative work with the Faculty is needed in order to expand the lab offer to more courses, on some of them, this may prove increasingly challenging.
  - *On Projects Workshop:* There is still a considerable gap of technical knowledge and expertise in order to get a fully integrated project done right, it is necessary to create a knowledge base the students can start from.
  - *On Nano Degree Program:* Critical factors for project success are project documentation, communication and organization. The Nano Degree is to include lessons on these topics starting next semester.

Acknowledgement

The work described in this Paper and the initiatives deployed have been made possible thanks to the support of Dr. Roland Vargas, head of the Industrial Engineering Department and Prof. Juan Carlos Chávez, in charge of the Design Engineering Lab, a branch of the Fab Lab in UTEC.

References

Barron, B., Darling-Hammond, L., (2008) *Teaching For Meaningful Learning: A review of Research on Inquiry-Based and Cooperative Learning,* Edutopia, retrieved from https://www.edutopia.org/pdfs/edutopia-teaching-for-meaningful-learning.pdf on July 25, 2017.

Larmer J., Mergendoller J., Boss, S. (2015) *Setting the standard for Project based Learning,* Association for Supervision and Curriculum Development.

Rotman D., Preece J., Hammock J., Procita K., Hansen D., Parr C., Lewis D., Jacobs D. (2011) *Dynamic Changes in Motivation in Collaborative Citizen-Science Projects*, *Proceedings of the ACM 2012 conference on Computer Supported Cooperative WorkPages 217-226*

Tranquillo, J.(2015). A Product Archaeology Canvas. Paper published in The Journal for Engineering Entrepreneurship, Volume 7, Issue 2. Available at: http://www.jeenonline.com/Vol7/Num2/JEEN%20Paper%202W.pdf

Tranquillo, J., Kline, W., Hixson, C.(2016). Making Sense of Canvas Tools: Analysis and Comparison of Popular Canvases. Paper Presented at the 2016 ASEE Annual Conference & Exposition, June 26 – 29, 2016.