An Implementation of Project-Based Learning in the Dynamic Systems and Control Course

Kilkenis Fuenmayor, Benito Fernández and Agustin Marulanda

***Abstract*—This work describes our effort implementing Project-Based Learning (PBL) in the ME-344 Dynamic Systems and Control undergraduate course at The University of Texas at Austin, in which the students acquire capabilities to model, simulate, and analyze dynamic systems with different kind of systems, such as mechanical, electrical or hydraulic. In the projects assigned, the students are expected to integrate into practice different theoretical concepts discussed in the course. The aim of this study is to assess the impact of the PBL strategy in the ability of the students to resolve engineering problems and their acquired generic skills by the final report and a survey at the end of the course. The results show that instructors and students agree with the PBL implementation.**

***Index Terms*—Project Based Learning, Dynamic Systems and Control, generic engineering skills, facing real-world problems, engineering education.**

I. Introduction

TRADITIONAL learning in engineering focuses on knowledge dissemination, where the instructor introduces a topic in a lecture, derives mathematical models, gives to the students practice problems, and finally assesses their abilities through exams [1]. In this method, the instructors transmit their knowledge to students while the latter try to acquire it. However, students never question themselves why this knowledge is important to their future career or what those models represent in real life. Through this traditional learning method students are not able to handle uncertainty, make decisions, think as part of a team in a social process, and communicate in effective ways.

In recent years, articles appeared in the literature showing that engineering students need to develop transversal skills, such as communication, leadership and teamwork, besides technical knowledge. This means that is necessary to incorporate more "human" skills and professional practice into the engineering curricula [2]. Warrington *et.al.*, in the report Vision 2030 [3] published by The American Society of Mechanical Engineering (ASME), argue that successful engineers will be individuals who, in addition to technical knowledge, have skills in communication, management, global team collaboration, creativity, and problem solving. This idea suggests that the engineering curricula should focus not only on developing in student's knowledge, but also skills and attitude. *Skills* might be understood as the engineer's ability to manage and apply their knowledge, and *attitude* might be interpreted as the personal values which influence the engineer's behavior [4].

Some learning methods have been applied in engineering education with the intent to fulfill this requirement. Problem-based learning and Project-based learning are two instructional methods that can be used to develop general skills in engineering students. These methods have been discussed and reviewed in the literature [5] [6] [7] [8], assessing and comparing different engineering courses.

The Problem-Based Learning comes from medicine and is widely used in that field. In the problem-based learning technique, students work with classmates to solve complex and real-world problems to find a suitable solution with instructors acting as facilitators [1]. Mills and Treagust [2] say that although this method has been adopted for engineering programs it may be a partial answer for resolve the critical issues of engineering education. In the engineering environment it seems like the project-based learning is a more proper method.

The Project-Based Learning begins with an assignment to carry out one or more tasks that lead to a final product (a design, a model, a device, or a computer simulation). The students must present a written or oral report summarizing the methodology used to generate the product. This strategy also develops in students some generic skills such as team working, communications, and leadership [1] [9]. These generic skills are developed since the students are asked to work in groups; they need to be assertive in communicating, respectful with their peers, and properly manage their time, to achieve the goals in the programmed deadline.

Even though both strategies are based on self-direction and collaboration, project-based learning is more appropriate in order to develop the required engineering competences, due to the fact that project tasks are closer to the reality in the professional environment and is more directed to the application of knowledge that problem-based learning [2].

This work describes our effort implementing PBL trough two projects in the Mechanical Engineering Department's ME-344 Dynamic Systems and Control course at The University of Texas at Austin. During the 2015 Fall semester, two projects were assigned. In the first project, students had to model, simulate, design experiments, estimate parameters, and analyze the system response of a micro wind turbine. In the second, they have to identify, design, and implement a position and velocity control of a servomechanism. This study aims to assess the students' feedback about the

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implementation of this strategy via a survey at the end of the course, and assess the students' abilities to resolve engineering problems and their generic skills acquired trough a final report.

Next section gives an overview of the undergraduate course which PBL was implemented. In section III, we describe the projects assigned to students and the different tasks and procedures that they had to accomplish. Then, in section IV it is explained the methodology used in order to assess the effectiveness and acceptance of the strategies by students. After that, the students' feedback are showed and analyzed in sections V. Finally conclusions are presented.

II. ME-344 Dynamic Systems and Control

The objective of the ME-344 Dynamic Systems and Control course (ME-344DSC) at The University of Texas at Austin is to introduce techniques to model physical systems and its performance using energetically correct tools and system response analysis, in both time and frequency domain. The major motivation is for an experimental perspective to modeling, design, and control of mechatronic systems. The students acquire abilities to model, simulate, and analyze dynamic systems with different kind of systems, such as mechanical, electrical or hydraulic. ME-344DSC includes subjects like that: 1) Nature of physics and scientist experiment to derive models of reality, as well as, reasons for modeling and types of models. 2) Derivation of system dynamics' equations through energetic principles using Bond Graph. 3) Determinate the dynamic response of systems using state-space equations and transfer functions, and total response in time and frequency domains. 4) Fundamentals of control systems analysis and system design.

III. Project description

Two projects were assigned in the course with the purpose of covering several subjects. The students are expected to integrate into practice different theoretical concepts discussed in the course. In the first project, they have to work with a micro-wind turbine, and in another, they have to study how to control a DC Motor.

A. Wind Turbine Project

The system consisted of a mechanism to transfer eolic energy into mechanical energy, and from that into electrical energy. A 3D-printed model of a Savonius vertical axis turbine built in the Advanced Mechatronics Laboratory (AML) was used as the mechatronic system under study. A fan generates kinetic energy that produces torque acting on the turbine blades, and it responds by changing the angular velocity on the turbine. This rotational energy is transformed to electricity energy by a generator connected to the wind turbine axle. Figure 1 shows the Savonius vertical axis turbine built in the AML. An anemometer and a tachometer were supplied to measure wind velocity and angular velocity, respectively. Furthermore, a data acquisition system using a *MyRIO* equipment and *LabVIEW* was available to collect experimental data.

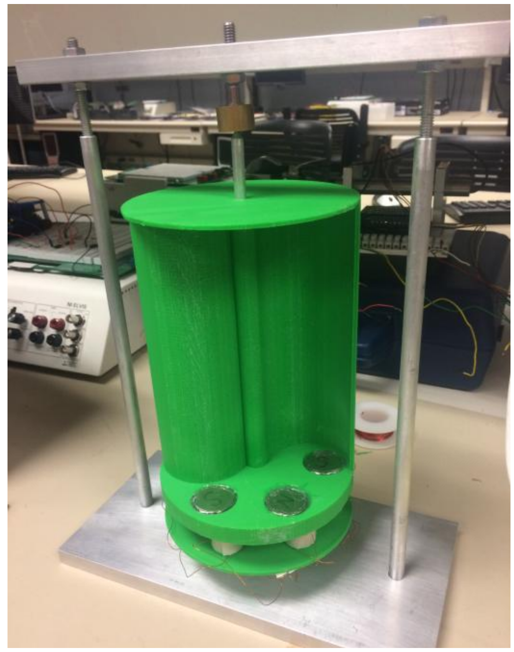

Fig. 1. Savonius vertical axis turbine built in the AML

Students had to write a report that described the methodology and results of the following items:

1) Problem Definition: Students carried out a literature search of wind turbines in order to understand the physics and clearly describe the geometry of the system and the assumptions made for modeling.

2) Bond Graph: In this part, students had to explain how their Bond Graph modeled each element of the Savonius wind turbine.

3) State Equations: Based on the Bond Graph model, the students derived the equations of motion composing the mathematical system model. The number of equations of motion corresponds to the number of integral causality which is the energy storing elements present in the Bond Graph, and also the order of the system.

4) Sensitivity Analysis: Based on the mathematical model that students derived in the previous section, they were asked to simulate and register the system performance when a parameter is changed. This was so they realized the sensitivity of the different model parameters.

5) Design of experiments (DOE): In this part, DOE is used to set up specific experiments that make possible the identification of system parameters. As such, students may try different experiments (steps, impulses, sinusoidal, etc.) and see how the system response varies when the parameters change. Students must justify what experiments to perform and how the experiment will help them obtain the unknown parameters, as well as, identify sources of uncertainty in the model and experiments.

6) Parameter Tuning: Students had to adjust the parameters based on the sensitivity analysis that they did before to establish a mathematical model that approximate better the wind turbine system and the experimental results from step (5).

B. DC Motor Control Project

This project intends to be an application of the skills students acquired during ME-344 Dynamic Systems and Control course. The purpose is to integrate concepts of control by investigating the characteristics and response of a DC servo motor. The system under investigation consisted of a DC motor equipped with a servo motor driving a disc load from Quanser. The on-board amplifier that drives the motor on the module is powered by an independent 24 DC power supply. The motor input is a voltage with a range of (+/-)24 V. The system has an encoder that measures its position, a digital tachometer that measures its speed and a current sensor to measure the actual current being fed into the motor. The actual DC Motor Control module is designed to operate on the *NI-ELVIS* platform from National Instruments (NI). The *ELVIS* unit is connected to a NI's Data Acquisition card inside the PC. Some Virtual Instruments (VIs) developed in *LabVIEW* interact with the data acquisition card to read encoder, tachometer and current sensor signals, and control the voltage to motor.

Fig. 2. DC motor system on the Elvis

The project consisted of the following activities: Modeling, Speed control, Position control, and PID control.

1) Modeling: Students had to construct a Bond Graph model for the whole system and determined the possible transfer function. Then they had to determine the unit step response of the system using the previous transfer function. Two Virtual Instruments were supplied in order to estimate the actual parameters of the DC motor system.

2) Speed Control: The objective of this section was to study a proportional-integral control system that regulates the speed of the DC motor. Students were asked to review the mathematical model of a DC motor and identify its physical parameters. Then, students used the NI-ELVIS platform equipped with a QNET-DC motor control module from Quanser, available in the AML, to simulate the speed control designed.

3) Position Control: In this section, a closed-loop control system that regulates the position of the DC motor was required. Once the model was validated, students used it to design a proportional-derivative controller and simulate it in the AML.

4) PID Control: The disturbance effects using PD and PID controller were analyzed in this section through direct manual interaction or a simulation using a control switch in the virtual instrument (VI) provided by the instructor.

IV. METHODOLOGY

To achieve the course's objectives two projects were assigned. One of the projects was assigned as a mid-term project. The 100 students were given six weeks to submit their reports. The professor gave the instructions and orientations about how to carry out the project in two lectures. The students worked in groups of two or three, to develop experiments in the lab, according to the instructions delivered. Then, they prepared their reports at home. The teacher's assistant helped students to do measurements in the lab and clarified doubts about the experiments.

The second project was assigned in the last part of the semester. The students were given three weeks to do the experiments and submit the report. One lecture was spent explaining the instructions for the project. The software that the students needed to manage the project was available in the UT-cloud and in the AML.

A survey was applied at the end of the course to collect the student feedback about the Project-Based Learning and its implementation. This survey was a questionnaire formed by 16 questions, each scored on a five-point range response scale: Strongly Disagree (1), Disagree (2), Neither Agree or Disagree (3), Agree (4), and Strongly Agree (5). This questionnaire was structured in three topics: ability to apply theoretical concepts, generic skills, and facing real problems.

Table 1. Questions about the application of theoretical concepts

Statements	From Strongly disagree to strongly agree
1. The project assigned helped me apply different theoretical concepts discussed in class	1 2 3 4 5
a) The project let me understand better the Bond Graph technique	1 2 3 4 5
b) The project developed my abilities to design experiments	1 2 3 4 5
c) The project developed my abilities to estimate parameters	1 2 3 4 5
d) The project developed my abilities to analyze the system response	1 2 3 4 5

In regards to the first topic, students were asked to answer the questions showed in Table 1. The idea was to determine whether the project helped the students to apply concepts taught in class, such as Bond Graph techniques, experiment's design, parameter's estimation, and system response's analysis.

Through the questions in Table 2 the students were consulted about the generic skills that they acquired while working in the project.

Concerning with the topic 3, the students were asked to answer the questions showed in Table 3. The projects represent real life scenarios, and attempt to raise awareness about the environment, highlighting the interest in renewable energies and in activities that are essential in the duties of an engineer.

Table 2. Question about generic skills that students improved

Statements	From Strongly disagree to strongly agree
1. Through this project I have improved some generic skills.	1 2 3 4 5
a) Through this project I have improved my oral communication skills	1 2 3 4 5
b) Through this project I have improved my writing skills	1 2 3 4 5
c) Through this project I have improved my team working skills	1 2 3 4 5
d) Through this project I have improved my time management skills	1 2 3 4 5
e) Through this project I have improved my creativity	1 2 3 4 5
f) Through this project I have improved my leadership skills	1 2 3 4 5
2. The Project Methodology allowed me to develop some skills that I wouldn´t have developed with the classic methodology.	1 2 3 4 5

Table 3. Questions about facing a real-world problem

Statements	From strongly disagree to strongly agree
1. Facing this project has developed my problem solving skills	1 2 3 4 5
2. After this subject, I have a better understanding about how the wind turbine works	1 2 3 4 5
3. This subject is relevant in my your training as an engineer	1 2 3 4 5

V. Results and Discussion

A. PBL and theoretical concepts

The PBL is a helpful tool to encourage students to apply theoretical knowledge acquired during the course. The students were asked about how the projects helped them to integrate into practice different theoretical concepts discussed in ME-344DSC. The results show that 67.19% of the students agree that the project assigned helped them to apply different theoretical concepts discussed in class.

As was described in a previous section, the course aims is to build up in students some abilities such as: Bond Graph technique, experiment's design, parameter's estimation, and system response's analysis.

According to the survey, 44.93% of the students agree that they got a better understanding of the Bond Graph methodology after they completed the project assigned. Additionally, 59.42% agree that they developed their abilities in how to design experiments. Finally, 52.17% and 65.22% state that this learning technique improves their abilities in estimate parameters and analyze the system response, respectively. Figure 3 shows the results to those questions.

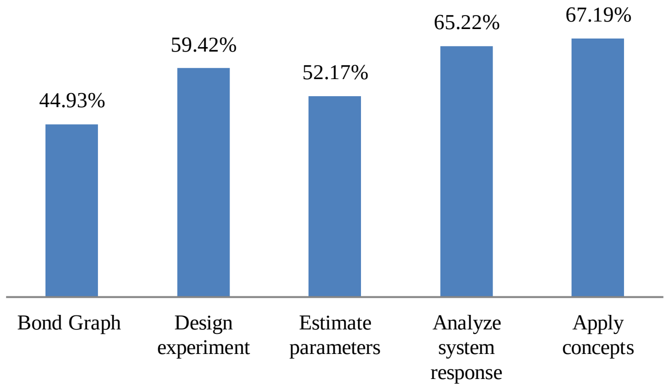

Fig. 3. Percentages about applying theoretical concepts discussed in ME-344DSC

Summarizing, most of the students think that PBL is a good learning strategy to help them in applying theoretical concepts into practice. Only the question about the Bond Graph technique got a percentage below 50; that could be explained because the systems to model were too simple

B. PBL and generic skills

As it is showed in Table 3, students were asked whether the projects assigned reinforced some generic skills. The survey showed that 40.91% states that the projects helped them to develop some generic skills. Specifically, 45.59% of the students think that team-working skills and creativity improved after working in the project. Additionally, 50.72% of the students stated that the project methodology allowed them to strengthen some skills better than with the classic methodology. Regarding other skills, such as oral communication, writing, time management, and leadership, the percentage of students that agree are 11.5%, 25%, 36.23%, and 25% respectively. Those percentages are shown in Fig. 4. These questions got a low percentage, the reasons of that could be that they did not an oral presentation, they might present weakness and lack of confidence in how to write a report, and the groups were too small. These reasons could be take in account for coming researches.

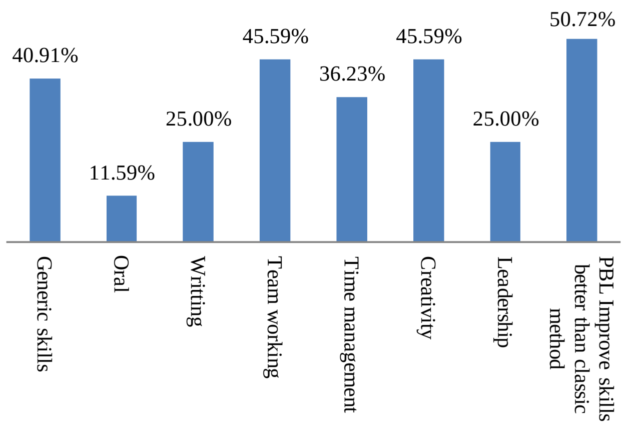

Fig. 4. Percentages about generic skills developed trough the projects

C. *PBL and facing real problems*

In the survey applied to students, they were asked if the project assigned had improved their problem solving skills; 61.76% agreed with this statement. Moreover, 75% of the students stated also that after this subject, they have a better understanding of how wind turbines work. Additionally, 69.12% of the students consider that this course is relevant for their training as engineers. Figure 5 shows the percentages of the questions about the problems solving skills, understanding about wind turbine and relevance of the course.

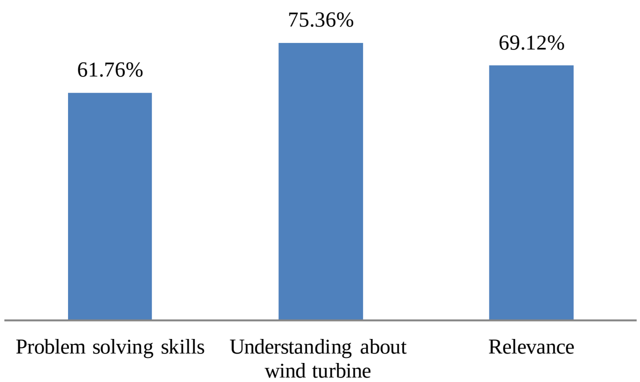

Fig. 5. Percentages about the ability to face real-life problems

According to these results, the implementation of projects on the ME-344 Dynamic Systems and Control course helps students to face real problems and find real solutions.

VI. Conclusions

A PBL implementation on undergraduate course has been presented in this paper. The impact of this strategy in the ability of the students to resolve real-world problem was assessed, as well as their feedback about this strategy.

According to the results, we can confirm that the implementation of the PBL in the course brought a positive influence. The information gathered trough the survey shows that most of the students agree that PBL helped them reinforce the theoretical concepts, strengthened their generic abilities and training in duties related to their engineering profession.

The instructors also agree the positive influence of the PBL in achieve the course’s goals. The quality of the reports is a proof of that. Most of the students could follow the guidance to accomplish successfully the stages of the project.

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