Teaching Control supported by Virtual Labs under a Competency-based curriculum

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Abstract– Competency-based education (CBE) is related, in simple words, with the possibility to create curricula whose main objective is to train students for the work reality, trying to minimize the time of adaptation of them in their future professional life. Although the philosophy behind this teaching paradigm is attractive, in practice its implementation entails an important effort for the academic institutions and teaching staff involved. In this context, this work presents a novel methodological proposal for teaching engineering competency-based courses; in this case, specifically applied on an automatic control course, providing details of its assessment structure and tools, learning activities developed (which integrates the use of virtual laboratories for online experimentation), and the method designed for the assessment of competencies.

Keywords—Engineering Education, Competencies, Automatic Control, Virtual Labs, Course Assessment.

I. INTRODUCTION

Academic institutions regularly face hard processes of "curricular redesign" and "curricula accreditation" in order to update the contents they teach, the educational models that support them and certify their quality.

Regarding the "curriculum redesigns", today there is a clear tendency to that academic institutions redirect their teaching methodologies towards a Competency-based Education model (CBE) [1]. In Chile, several academic institutions have already adopted this educational model [2, 3], especially in the areas of technical-vocational training and engineering, where it is necessary to train professionals for the industry who know how to act and interact in a pertinent way in real situations of working life.

However, the implementation of this educational model is not an easy task. The number of new pedagogical concepts, definitions and additional aspects to be handled by the teaching staff are not few and their correct application strongly depends on the deep knowledge that each teaching team member has regarding this educational model. Especially, with regard to the redesign of the course programs and their assessment methodology where, at least, the following issues should be considered: 1) how to define the competency model, 2) how to generate the evidence of its development, 3) how to collect them, and 4) how to evaluate them [4]. The latter should provide objective information on students' educational performance not only in terms of the contents studied, but also in relation to the development and achievement of competencies in the career graduate profile.

This challenge is even greater when the people involved in this process come from the field of Engineering, mainly because the teachers of this discipline, in general, do not have a "pedagogical" training of origin. The latter poses an additional problem since practically all existing literature on the subject is presented from the pedagogical perspective.

Additionally, a curricular redesign process also raises the need to update teaching practices. In this sense, the use of ICT tools (information and communication technologies) in the teaching processes in Engineering is also observed as a clear trend. Particularly, in the use of web tools known as virtual and remote laboratories (VRLabs) that allow conduct experiments on simulated physical processes (virtual) or real physical equipment accessed remotely through the Internet (remote). Usually, they are used as a practical complement to the theoretical study of a discipline, encouraging the self-learning of the students and providing them with more time for experimentation outside the laboratory [5].

On the other hand, the process of "accreditation of careers" involves a big effort for academic institutions, which must demonstrate clearly and with evidence, that the graduation profile and curriculum stated for a career are met rigorously. In the particular case of Chile, there are a set of requirements that higher education institutions must address (section A in the CNA-Chile accreditation forms [6]). Three of them are described below:

- Describe the mechanisms of monitoring and evaluation the curricula, which allow the career to demonstrate that its graduates effectively reach the graduate profile declared.
- Mention the subjects corresponding to each area of the curriculum and indicate the contribution of each of them to the graduate profile of the career.
- Point out the articulation between the objectives or learning outcomes existing between the different courses and the progress in achieving the graduation profile.

As can be observed, the accreditation process of careers requires absolute clarity regarding the assessment mechanisms used for the academic institution to ensure, objectively and with evidence, the fulfillment of the graduate profile. This latter being especially difficult for the case of the implementation of competency-based education models.

In the literature, many information can be found about the use of VRLabs to support teaching and learning activities in engineering courses. Likewise, the design and implementation of competency-based education models has been also widely described and published. However, despite all the information

available about both subjects, there is not a methodological framework specially conceived to guide the integration of VRLabs into learning activities which are specifically designed to train competences in engineering courses.

In this context, this paper describes the methodological approach which is currently being applied at the School of Electrical Engineering in the Pontificia Universidad Católica de Valparaíso PUCV (in Chile) for the assessment of competency-based engineering courses. Particularly, regarding the methodology used to integrate learning activities with VRLabs and where these are used to evaluate competences. The method is explained describing its implementation details in the course of Automatic Control of the new CBE program of the master degree on Electrical Engineering at the Pontifical Catholic University of Valparaíso, in Chile.

This article is organized as follows: Section II presents the automatic control course and its structure from the CBE model perspective. Section III presents the network of virtual and remote laboratories UNILabs, which provides the VRLabs used in this experience. Section IV describes two of the virtual labs which were used in the automatic control course for performing learning activities. Section V presents some details of the competency assessment model applied. Finally, section VI provides some conclusions and future work.

II. COMPETENCY-BASED CONTROL COURSE

A. About the course

The Automatic Control course is part of the new competency-based study program of the master degree on Electrical Engineering at the Pontifical Catholic University of Valparaíso PUCV, in Chile. In the previous curricula (not competency-based), the course was traditionally evaluated by three exam-like assessment tools. The weight of each of them regarding the final course qualification was: AT1 (30%), AT2 (35%), AT3 (35%).

This course is fundamentally theoretical and it has been redesigned to be taught by competences.

B. Competency-based curricula

As a consequence of the new competency-based study plans in the School of Electrical Engineering at PUCV [7], a redesign process of all course study programs has been carried out. In the case of the Automatic Control course, such redesign was done thinking on include experimental learning activities in order to put the theory in practice. At the same time, a new evaluation structure was defined in order to provide clear evidence about how the course contents and competences are going to be assessed.

The graduate profile of the study program promotes a total of 20 competences, which are classified in fundamental (12), disciplinary (6) and professional (6) training competences. The Automatic Control course contributes developing two of them (C_{12} and C_{13} hereafter), especially those related to developing capabilities for analyzing and designing automatic control

systems. Subsequently, to develop these competences three learning outcomes were defined (LO_{12_1}, LO_{12_2} and LO_{13_1} hereafter). These latter are stated as follows:

- Students will be able to apply methodologies of control system analysis to solve electrical engineering problems.
- Students will be able to apply methodologies of control system design to solve electrical engineering problems.
- Students will be able to use computational tools to simulate and analyze control systems.

C. New assessment structure

For the assessment of the Automatic Control course, it is proposed to carry out two summative tests that weight 80% in the final grade (AT1: 40% and AT2: 40%) and the development of a "knowledge integration activity" (AT3) that weights the remaining 20%. This last learning activity will include the use of virtual and remote laboratories (VRLabs) for conducting online experiments. This allows students to apply their control designs on systems close to reality, carrying out typical experiences of analysis, design and validation of control systems. For this purpose, the UNILabs web platform is used [7], which has online resources specially designed for higher education courses in the field of Sciences and Engineering. Next section describes the UNILabs platform and the VRLabs which have been used in the automatic control course.

III. UNILABS: UNIVERSITY NETWORK OF INTERACTIVE LABORATORIES

Virtual and remote laboratories are web applications that allow the realization of experiments on simulated physical processes (virtual) or real physical equipment accessed remotely through the Internet (remote). Usually, they are used as a practical complement to the theoretical study of a discipline, encouraging the self-learning of the students and providing them with additional time for experimentation outside the laboratory [8].

The use of virtual and remote laboratories in the field of Engineering Education in general and, in particular, the control engineering [9], is a reality in many universities around the world [10]. An interesting experience in the application of this teaching method was the interuniversity network called AutomatLabs [11]. This project generated a product based on the use of the Internet (using virtual and remote laboratories) that was successfully integrated and used in the Automation I courses of seven Spanish universities in two pilot tests carried out in the years 2009 and 2010. The system was highly well valued by the student community, observing in them a remarkable improvement in the learning of the fundamental concepts of control theory, evidence that encourages the application of this strategy for teaching innovation projects.

UNILabs (University Network of Interactive Labs) is an extension and update of AutomatLabs (see Figure 1). In this network, the number and nature of virtual and remote laboratories available has grown with respect to its predecessor,

up to a total of more than thirty. On the other hand, the old web portal became to a modern and open source LMS (Moodle) that allows, among other things, to define learning competences and track the acquisition of them by the students. In UNILabs, nine universities of different types (face-to-face and distance) and from different places (several regions of Spain and Chile) participate, as well as consumers of resources (virtual and/or remote labs, complete courses …), as technology developers (contributions to the software tool EjsS, which laboratories are built with) or as developers and suppliers of courses and/or laboratories.

Fig. 1 UNILABS web platform.

Next section describes two of the virtual laboratories which are used in the "knowledge integration activity", its context of application and the typical control tasks requested by the teaching team for its development and assessment.

IV. Virtual Laboratories used

A. *Single Tank Control*

The level control of a tank or "single tank control" is a modeling and control problem typically analyzed in classical control courses. The system consists of a liquid tank with an outlet or discharge section, into which a variable fluid flow enters which is regulated by the action of a valve (see Figure 2).
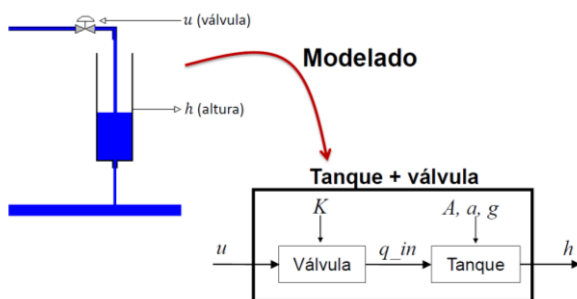

Fig. 2 Single tank system.

For this process, the following expression represents the non-linear differential equation of the tank system that models the conservation of the mass, where h represents the height of the liquid inside the tank, A the area or section of the tank, a the area of the drain hole, g the acceleration of gravity and u the voltage applied to the pump that regulates the liquid input flow to the tank.

$$\frac{dh}{dt} = \frac{K_m u}{A} - \frac{a\sqrt{2gh}}{A} \quad [m/sec]$$

Where:

K_m: Flow-volt ratio of the pump ($m^3/volt \cdot sec$)
u: Voltage applied to the pump motor ($volts$)
g: Gravitational constant (m/sec^2)
h: Level of liquid inside the tank (m)
a: Section of the drain pipe in the tank (m^2)

B. *Virtual-Lab of the Single Tank*

Based on the mathematical model, a virtual laboratory was designed and developed through which the students will carry out a set of practical experiences requested by the teaching team. Figure 3 shows the appearance of the virtual laboratory that has been created.
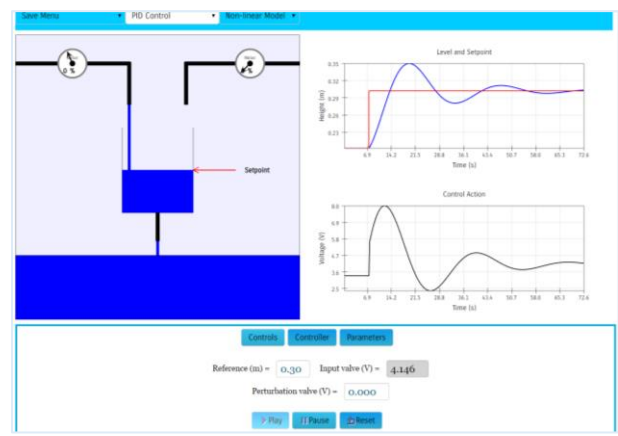

Fig. 3 Virtual laboratory of the Single tank.

The laboratory allows performing simulation experiments both in open loop and closed loop. When working in a closed loop, it is possible to switch between a PID control and a conventional lead-lag compensator such as:

$$G_{pid}(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s \right) \quad ; \quad G_c(s) = K_c \left(\frac{s+z}{s+p} \right)$$

A typical task with this application is to perform an analytical design of a controller or compensator to work on an operation point and then verify its performance by conducting multiple control experiments on the simulated system. The application also allows comparisons of the designs on the

linearized system or the original non-linear system. The application was developed in JavaScript programming language, using the EjsS tool [12], and thus allowing its easy integration and execution embedded in a standard web browser.

C. DC Motor Control

The speed or position control of a DC motor is a control problem widely studied and applied in the domestic and industrial field. The DC Motor is composed of three coupled stages: the electric, the magnetic and the mechanical. The voltage applied to the electrical circuit of the motor generates a magnetic field which, at the same time, causes the mechanical turn of the rotor as shown in Figure 4. In this sense, a DC motor basically converts electrical energy into mechanical energy by using electricity and a magnetic field to generate torque, which spins a rotor that produces mechanical work.
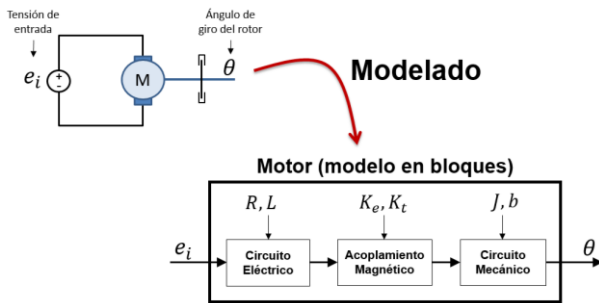

Fig. 4 The DC Motor system.

To obtain the analytical model of the DC motor, it is necessary to know the internal model of each subsystem that constitutes it and its relationships. Figure 5 shows the detailed circuit diagram of the DC motor, which is manipulated by induced, that it will be introduced in this activity.
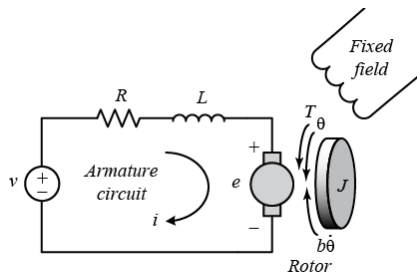

Fig. 5 Circuit of the DC motor manipulated by induced.

According to the diagram in Figure 4, it is assumed that the motor input is a voltage source that is applied to the motor armature, while the output is the position or rotation speed of the motor shaft. Moreover, it is also assumed that the rotor and the shaft are rigid.

Subsequently, the equation that governs the dynamics of the electric stage is as follows:

$$R \cdot i + L \frac{di}{dt} + e = e_i$$

Where:

R: Armature electrical resistance [Ω]
L: Electrical armature inductance [H]
i: Armature current [Amp]
e: Induced voltage [volts]
e_i: Voltage applied to the motor armature [volts]

On the other hand, the equation that governs the dynamics of the mechanical stage is expressed as follows:

$$J \frac{d^2\theta}{dt^2} + b \frac{d\theta}{dt} = T$$

Where:

J: Moment of rotor inertia [$Kg \cdot m^2$]
b: Viscous friction constant of the motor [$N \cdot m/(rad/s)$]
T: Mechanical torque developed by the motor [$N \cdot m$]
θ: Rotation position of the motor shaft [rad]

Then, the equations that govern the coupling stage of the motor are:

$$e = K_e \frac{d\theta}{dt}$$

$$T = K_t \cdot i$$

Where:

K_e: Electromotive force constant [$Volts/(rad/s)$]
K_t: Motor torque constant [$N \cdot m/Amp$]

In summary, all previous equations represent the dynamics of the DC motor, where R, L, J, b, K_e, K_t are the characteristic parameters of the motor and $e_i, \theta, \dot{\theta}$ are the dynamic variables DC motor under study.

D. Virtual-Lab of the DC Motor

Figure 6 shows the appearance of the DC Motor virtual laboratory that has been created.

Fig. 6 Virtual laboratory of the DC Motor.

In a similar way than the previous virtual laboratory (single tank), this laboratory allows performing speed and position control experiments in both open and closed loop. The application is specifically intended to train PID controller design considering practical issues of implementation such as: windup problem, noise in derivative action, real time coding of PID controller, bump-less switching, among others.

V. COMPETENCIES ASSESSMENT

A key aspect in the assessment of competency-based engineering courses is the definition of the assessment structure. In the particular case of this work, it was considered to assess on the one hand, the content of the course and on the other, the level of achievement of competences.

The first step to define the evaluation structure was to describe the relationship between the learning outcomes and the competences of the course, such as shown in Table I. In this sense, the level of achievement of the competence C_{12} is assessed by measuring the progress of the students regarding the learning outcomes LO_{12_1} (related with control systems analysis) and LO_{12_2} (related with control systems design), both contributing with the same weight (50%) towards the competence. On the other hand, something different happens for competence C_{13}, which is developed with only one learning outcome LO_{13_1} (related with control systems simulation), therefore contributing with a 100% to the respective competence. The weights of learning outcomes should be chosen according its relevance for a competence.

TABLE I
COMPETENCE AND LEARNING OUTCOMES RELATIONSHIP FOR THE AUTOMATIC CONTROL COURSE

Competency	Learning Outcomes	Weight (%)
C_{12}	LO_{12_1}	50%
	LO_{12_2}	50%
C_{13}	LO_{13_1}	100%

For the assessment of the achievement of competences, the work proposes to assess the learning outcomes with an ordinary qualification (numeric scale from 1 to 7) in each assessment tool of the course, using an evaluation rubric for these purposes. In this way, the student will obtain a final grade for each competence based on the grade obtained for the learning outcomes, considering that LO_{12_1} is measured by AT1, LO_{12_2} by AT2, and LO_{13_1} by AT3. The achievement of competences was defined with three levels: 1) achieved (when the final qualification of the competence is between 5.5 and 7.0), 2) moderately achieved (when the final qualification of the competence is between 4.0 and 5.4) and 3) not achieved (when the final qualification of the competence is between 1.0 and 3.9). This is the competence achievement scale proposed by the teaching team, which can integrate more levels as required.

Finally, it must be mention that a key aspect in the effectiveness of this model is the correct preparation of the assessment tools from the perspective of its intentionality. For example, when preparing the AT1 of the course, each question must be designed in such a way that they can be related not only to the content of the course but also to the learning outcomes that should be measured. As a result, there will be a total score regarding the course content evaluated and, additionally, a qualification associated with each learning outcome measured on it. In summary, each assessment tool should be designed with intentionality towards the learning outcomes what will allow qualifying with a numeric scale both the abstraction of course contents and the level of achievement of learning outcomes and competences.

VI. CONCLUSIONS

An innovative methodological proposal was presented for the assessment of the Automatic Control course that is part of a competency-based education model. The proposal presents two interesting elements. Firstly, it integrates the use of virtual and remote laboratories in one of the assessment tools of the course. By using them, students perform experiments on simulated models of real processes typically used in the industrial field, encouraging the students who do not usually have this type of activity in theoretical courses. Additionally, this allows students to arrive better prepared to the next course in the study plan the "Automatic Control Laboratory" that follows the theoretical control course in the analyzed curricula.

On the other hand, a methodology was presented for the course assessment in the context of a competency-based curricula. Although this work presents its application to the course of Automatic Control, it can be used in engineering courses of any discipline that integrates theory and practice in its formative process.

This proposal is currently being applied in a regular course of Automatic Control at the School of Electrical Engineering of the PUCV. We expect to get valuable information to study and measure the final impact of this teaching innovation in the students of this discipline.

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