PROJECT-BASED LEARNING APPROACH FOR CONTROL SYSTEM COURSES

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RESUMO

Abordagem de Aprendizagem Baseada em Projeto Para Cursos de Sistemas de Controle
Este artigo apresenta a concepção e o desenvolvimento de cursos de sistemas de controle num programa de graduação usando a abordagem Project-Based Learning (PBL), quando o currículo usa educação tradicional. O artigo apresenta um esboço completo de cursos de controle que leva em conta a definição do problema, a duração do projeto, os recursos de apoio e avaliação do aluno. Nesta abordagem, os alunos são organizados em equipes para desenvolver um projeto destinado a encontrar a solução para um problema de controle. A abordagem é baseada na colocação de um desafio profissional ao curso, de modo que os alunos aprendem os tópicos, enquanto eles resolvem o problema e desenvolvem competências transversais necessárias para enfrentar os novos desafios de controle. A abordagem utiliza avaliação por pares e auto-avaliação das atividades para avaliar as habilidades, o conhecimento e observar o desenvolvimento de competências transversais.O impacto da abordagem proposta é avaliada por meio de pesquisa e observação do desempenho dos alunos. Aspectos sobre o projeto de pesquisa e os resultados da pesquisa são apresentados analisando a contribuição da abordagem proposta para desenvolver habilidades como trabalho em equipe, auto-aprendizagem a resolução de problemas e habilidades de comunicação.

PALAVRAS-CHAVE: aprendizagem baseada em projetos, educação de controle, avaliação entre pares, competências transversais.

ABSTRACT

This paper introduces the design and development of control system courses in an undergraduate program by using Project-Based Learning (PBL) when the curriculum uses Traditional Education. The paper presents a complete outline of control courses that takes into account the problem definition, project duration, support resources and student evaluation. In this approach, students are organized into teams to develop a project seeking to find the solution to a control problem. The approach is devoted to placing a professional challenge into the course, so students learn the topics while they solve the problem, and develop the transversal skills needed to face the new challenges of control. The approach uses the peer-assessment and self-assessment activities to evaluate abilities, knowledge, and observe the development of transversal skills. The impact of the proposed approach is evaluated by using a survey and observing the student performance. Aspects about the survey design and survey results are presented analyzing the contribution of

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the proposed approach to develop skills like teamwork, self-learning, problem solving and communication abilities.

KEYWORDS: Project-based learning, control education, peer-assessment, transversal skills.

1 INTRODUCTION

The current challenges of engineering demand an education that allows engineers cross the boundaries of their professional fields. The new control problems need contributions from different disciplines since currently the control systems cover a wide range of applications that includes the design of household appliances, sophisticated industrial controllers, benchmarks in the developing research areas as the biotechnology, renewable energy sources, etc.. A good example of these achievements and trends are remarked in the report of IEEE Control Systems Society titled 'The Impact of Control Technology', (Samad and Annaswamy, 2011).

Therefore, control engineers should be able not only to analyze the theoretical and technical issues of the control solutions, but also to observe their relationship with the context and other professional fields. The new challenges require, among others, that engineers develop skills as long-life learning to remain competitive in a professional field ever changing, communicate ideas to others, make decisions, learn by themselves, save the environment, evaluate the social impact of engineering solutions and work with others.

The reflection about how to improve the control education always has been an important issue, for example, in reference (Kheir et al., 1996), authors discuss about the control education as discipline, which is focused on knowing four basic concepts, namely, system dynamics, stability, feedback and compensation. Authors present the control pedagogical problem based on two streams; one is mathematics-based education to understand the concepts and another one is the discipline-based education regarding to the control system skills sought by industry. About the role of university, authors state that 'the industry wants educators to provide technical foundations that will enable engineers to remain current and competitive in an ever changing advancing, global market place'.

Likewise, (Antsaklis et al., 1999) presents reflections from 'NSF/CSS Workshop on New Directions in Control Engineering Education'. The document summarizes the workshop's results by five categories that include undergraduate curriculum issues, laboratory issues and World Wide Web (WWW) technologies. Other ideas discussed in workshop's recommendations about control education are: to encourage the development of new courses and course materials, develop follow-up courses at the undergraduate level that provide the necessary breadth and depth to prepare students both for industrial careers and graduate studies, promote laboratory development and make experimental projects an integral part of control education for all students, (Antsaklis et al., 1999).

Taking into account recommendations presented in (Kheir et al., 1996) and (Antsaklis et al., 1999), the main challenge in control education implies to design a suitable curriculum so that students are provided with practical and theoretical skills for a good professional performance. For example, in applications of industrial automation besides of modeling, analysis and design of the process, it is necessary to know: the customer requirements, technology to implement, solution cost, performance of designed control strategy, execution time, human resource management, interdisciplinary teamwork, among others. This means that control engineers should propose integral solutions for the control problems; therefore, it is not enough learning the control foundations and developing the technical skills, control education should provide a learning environment that promotes the development of transversal skills.

Another relevant aspect of control education, that is also dealt by (Kheir et al., 1996) and (Antsaklis et al., 1999), is the support resources. According to (Bencomo, 2004), the future of control education aims to involve information technology. Currently, the use of new technologies and web-based resources is ever most common in control courses, there are many works devoted to design and apply web-based resources like specialized platforms, simulators and tools for remote experimentation in control courses. Some examples of recent works about the development of web-based resources for control education are presented in (Qiao et al., 2010; Vicente et al., 2010; Ramos-Paja et al., 2005; Martí et al., 2010; Farias et al., 2010). Compared to actual didactic equipment, the web-based resources are an inexpensive choice for being used in the lab practices, since these can be accessed simultaneously by many users from different places and include useful tools like content repositories, links, wikis, forums, etc.

In short, control education should *i)* balance the mathematics-education and discipline-education (theory and practice), *ii)* be according to needs of industry and requirements for working in this professional field, *iii)* stimulate the development of transversal skills and *iv)* use new technologies and web-based resources.

The work introduced herein devotes mainly to curricular issues describing the design and development of control system courses by using Project-Based Learning (PBL) as an option to develop control courses that seeks to achieve goals presented above. This work also aims to strengthen the engineering education encouraging students to develop transversal skills from control courses and facilitate the understanding of control systems, which stand out as having great mathematical abstraction that sometimes hinders the learning of topics for some students.

1.1 Why use PBL in control?

PBL begins in the work of John Dewey (1859-1952), Dewey advocated for an education that balances the knowledge and the interests and experiences of the students. In 1918, William Heard Kilpatrick (1871-1965), collaborator and colleague of John Dewey, published the book entitled 'The Project Method'. In the late 1960's, PBL as problem-based learning was developed as an educational approach in the health programs at MacMaster University, soon after, PBL was used by other medical programs like Maastricht in Holland and New Castle in Australia and it was adapted for other disciplines including engineering.

PBL has been considered a good approach in improving education in engineering because this approach facilitates learning difficult subjects, encourages active learning, and allows developing both the engineering skills and transversal skills by using a 'learning environment that simulates a real professional challenge'. The reference (Kolmos et al., 2008), presents a state of art on effective facilitation in PBL and some aspects that demonstrate the effectiveness of PBL on learning. These are, promoting deep approaches of learning instead of surface approach, improving active learning, developing criticality of learners, improving self-directed learning capability, increasing the consideration of interdisciplinary knowledge and skills, developing management, collaboration and communication skills, developing professional identity and responsibility development and improving the meaningfulness of learning.

PBL has been used with remarkable success in important universities throughout the world, for example: Aalborg University in Denmark (Kolmos, 2004), where the UNESCO Chair in Problem Based Learning offers currently a global space for researches and academics interested in PBL, the University of Louvain (Frenay et al., 2007), and Sherbrooke University in Canada (Bédard et al., 2007). There are several experiences using PBL in engineering subjects such as circuit analysis (Costa et al., 2007), digital signal processing (Nelson, 2006a; Nelson, 2006b), instrumentation and measurement (Mukhopadhyay, 2007), digital and analogical electronic circuits (Northern, 2007; Nerguizian and Rafaf, 2006; Perera, 2002), power engineering (Mota et al., 2004), computer engineering (Garcia-Robles et al., 2009), etc. In Latin America, there are experiences in control systems at Universidad de los Andes in Colombia (Duque et al., 2003) and at Instituto Tecnológico de Estudios Superiores de Monterrey in Mexico (Morales-Menendez et al., 2006).

The papers (Duque et al., 2003; Morales-Menendez et al., 2006; O'Mahony, 2008; Ramos-Paja et al., 2005) are centered on the application of PBL in control education. The first two ones deal with approaches that use Problem-based Learning and other approaches (e.g. teaching for understanding and cooperative work) for control learning; the third one describes an experience on the application of PBL in control, in which the PBL approach is examined from a cooperative learning theory. Finally, the last paper presents the design of web-based resources to learn control through PBL.

The work reported herein serves to three main purposes. Firstly, it presents an approach more focused on curricular issues of control engineering education and evaluation students than on the design or use of support resources or lab equipment. This work shows a complete PBL experience in control education considering aspects like the problem definition, project schedule, student team conformation, academic activity organization, lectures, support resources that include simulation and emulation, student evaluation, and course evaluation. The paper also details a proposal to plan academic and evaluation activities to apply PBL in control system courses, which can be adapted by other teachers in different engineering fields.

Secondly, it proposes an approach to develop transversal skills from control courses to offer students an integral learning environment that allows them to improve the knowledge retention and develop technical and transversal skills to face the new control challenges.

Thirdly, it contributes to the research on PBL in engineering that is currently enhancing and devotes topics like PBL models, PBL practice, methods for study of PBL, and PBL effectiveness to develop skills, etc., (see, De Graaff and Kolmos (2007), Du et al. (2009)). It is worth highlighting, that the proposed PBL approach is an example to apply PBL in engineering courses exploiting the resources already available in the university when the general curriculum does not use PBL. Furthermore, the paper presents a methodology to evaluate the impact of the proposed PBL approach through instruments like formats for the student evaluation and a survey to know the impressions of students.

The rest of the paper is organized as follows: in the second section the design of the course is described; aspects like problem definition, project organization, framework of the control system area, project-based learning implementation, and support resources are discussed. The third section presents the student evaluation. Finally, the student feedback and concluding remarks are presented.

2 DESIGN OF THE PROJECT-BASED LEARNING APPROACH

The description of the proposed PBL approach and its impact are dealt based on the experience developed in the control courses of the Electronics Engineering Program by Industrial Control Research Group at Universidad del Valle, Colombia.

2.1 Case study

The control system area in Electronics Engineering at Universidad del Valle has four courses in control systems, two courses in theory, and two courses in laboratory. Courses are developed in 18-week periods (one semester); the theoretical course has three academic credits and the laboratory course has one academic credit (In Colombia, one academic credit = 48 working hours of student).

The first level (one theoretical course and one laboratory course) corresponds to Foundations of Linear-Control Systems and the second level, also with two courses, corresponds to Analysis and Compensation of Linear Systems. In first level, students learn about system modeling, time-response analysis, and experimental design of PID controllers. In the second level, students learn analysis and design techniques for frequency response and root locus, along with pole-location control and control structures like cascade control, feed forward control, etc. In both levels, topics on analog and digital control are studied simultaneously in the state space and transfer function representation. The PBL approach is applied in both levels during the third year of the Electronics Engineering program.

The methodology for each level was designed as an integrated course of theory and practice; however, theory and laboratory are evaluated separately. This PBL approach is a blended approach; meaning that the methodology mixes elements and tools from Project-Based Learning with other approaches, for example, Lecture-Based Learning (LBL) and Hands-On activities. This blended approach is suitable for students because it familiarizes them with PBL when the rest of the courses in the curriculum use Traditional Education.

2.2 Project-Based Learning Implementation

2.2.1 Problem

The problem is the trigger of the learning process. The designed PBL approach is based on open problems, which are defined by faculty staff from three aspects: a variable, control targets, and the context of a process. The problems are assigned randomly to student teams.

The approach considers two kinds of problems, problems based on the specific context and problems defined from benchmarks or case studies. The first ones, have as target the control of a industrial variable, usually considering the local industry, and seek that students know and think over challenges of their context. The second ones use a laboratory prototype as experimentation resource, these are also contextualized in a real application but their main objective is deepening on a case study or benchmark. In both kinds of problems, students see the context as a reference for solving problems, but problems are not directly developed there. The experimentation resources also constrain the problem definition since the staff must evaluate whether problems can be solved by using prototype plants or throughout mathematical models, which are generally used for the first kind of problems. This is an example of problems used in the PBL courses:

“The sugar-cane factory has a process called clarification. In this process, lime is added to sugar cane juices to control the pH concentration of the juices. Design a control system to keep the pH concentration of the sugar cane juices near 7.” In this example, the variable is pH concentration; the control target is ‘to control pH concentration of sugar cane juices’, and the context is the sugar-cane factory.

The pH is a typical industrial variable and the problem context chosen is a sugar-factory, this kind of industry is a representative economic sector of the region where Universidad del Valle is located. Choosing nearby contexts is important because students easily establish contact with factories and those factories become resources of the approach.

2.2.2 Project

The project is the central element in the approach. All academic and evaluation activities are oriented by the project. In each control course there are four stages to develop the project. For Foundations of the Linear-Control System course, in the first stage, students describe the physical systems by identifying the elements of typical control loop; in the second stage, they find a system model; in the third stage they discuss the time response of the system; and in the last stage, students implement a PID control in their projects (see Figure 1). For Analysis and Compensation of Linear Systems courses, in the first stage, students analyze the system by means of root locus and frequency analysis; in the second stage, they design an analog PID controller; in the third stage, they design digital controllers like PID and RST; and in the last stage, students design state space controllers and observers. In the courses, the order of the topics is similar to the previous LBL courses; however, in the PBL approach, topics are learned according to the development of the project.

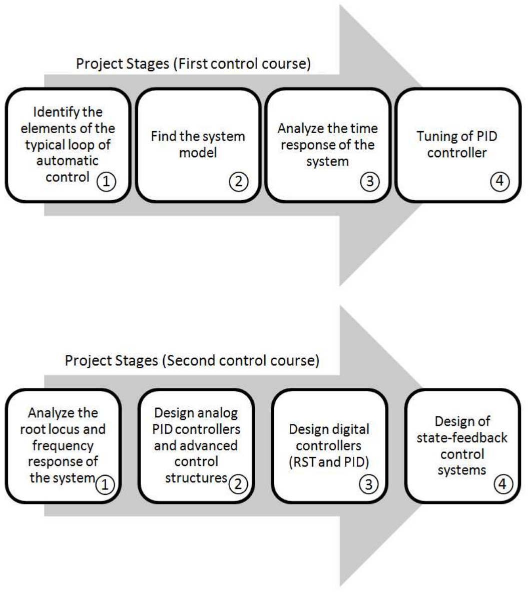


Figure 1: Project stages for the first and second level of control systems area.

2.2.3 Student Team and Staff

The project is carried out by teams of three or four students (student team). The teams are conformed according to the grade-point averages of students. Students with high averages were grouped with students with low averages to establish homogeneity among teams. The team conformation is kept for the semester. Students do not choose their teammates because - in real life - when engineers enter a company, they do not necessarily choose their coworkers.

Projects are rotated among the student teams (see Figure 2) because the approach seeks teams to work with different kind of problems and industrial variables, and use different experimental resources. Moreover, in the professional performance, it is usual for projects to be developed by several teams. The rotation of problems also allows defining peer-assessment activities among teams, which are described in the evaluation section.

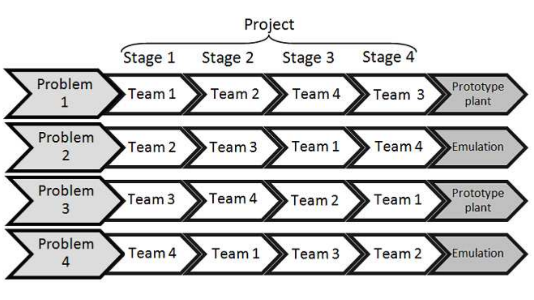


Figure 2: Rotation of problems.

The faculty staff is comprised by two teachers, one for theory and another for laboratory. Students have an expert on problem issues, who is not a teacher of the course. The expert is invited by teachers to participate as advisor for developing the project. The participation of this expert also allows students to discuss with professionals from other areas to strengthen their communication abilities. Also, some speakers are invited to explain specific topics.

2.2.4 Support Resources

All academic activities are coordinated through the institutional virtual campus that uses the Moodle educational platform. There, teachers and students receive and send written reports, documents, slides, grades, guidelines, etc. For experimental activities, student teams use prototypes of industrial plants, remote experimentation and real-time simulation (emulation).

In the automation laboratory at Universidad del Valle, students can work with industrial variables like pressure, temperature, pH, flow, level of liquids, position, and velocity. Pilot plants in other laboratories at the university are also used; for example, some projects have been developed in the structures laboratory in Civil Engineering, and others have been carried out in the food chemistry laboratory. In these labs, students can 'handle' actual measurement instruments and industrial controllers.

Otherwise, emulation and remote experimentation allow defining projects within new contexts, observing the dynamics of control complex problems from diverse nature, experimenting with non-available systems in the laboratory and observing the controller performance before its implementation in real contexts. For example, when the problem is solved by using models and students need to test and implement an actual control, they use emulation to connect hardware in loop with the models, (Fernandez-Samacá et al., 2010).

Emulation and remote experimentation are available in the platform called PERI (*Plataforma de Experimentación Remota para Educación en Ingeniería* – Remote Experimentation Platform for Engineering Education) (Ramírez et al., 2008), created by GICI and the Perception and Intelligent Systems Research Group (PSI) at Universidad del Valle. This platform has other remote resources like simulators, contents and analysis tools for systems.

2.2.5 Course schedule

The activities for each week are programmed according to both the project stage and the theoretical or practice activities. The course schedule is presented in the student guide; this document also contains objectives, problems, evaluation activities, competencies, and guidelines on assessment and application of the PBL approach.

In the theoretical course, the main activity is the tutoring; in the laboratory, activities center on training. In the tutoring activity, the teacher solves questions, explains some difficult topics to be learned by means of brainstorming, advises about the project work, conducts sessions to solve exercises before exams or quizzes to help students to study for evaluations, orients short lectures and develops Hands-On activities to learn concepts in a fun way.

The Hands-On activities, along with short lectures, are included to facilitate learning key concepts, present the main aspects of the theory, and improve the background theory of students. It is considered that this aspect is especially critical since the control area is the only one using PBL courses in the curriculum; the detailed analysis of this aspect is presented in Fernandez-Samacá and Ramírez (2011).

In the laboratory training, students carry out practices according to the project stages; these practices aim to develop the skills needed by students at each stage of the project. For theory, all students attend the classroom; whereas for training, the student group is divided into groups, which do not have any relationship to the student team in the project. The course schedule for the PBL approach is shown in Figure 3.

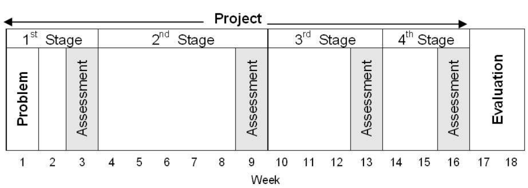


Figure 3: Distribution of the project stages and evaluation activities.

3 ASSESSMENT AND EVALUATION

The approach uses different instruments and activities for evaluation. Students are evaluated by their peers and their teachers. Also, the course uses self-assessment. Transversal skills like teamwork, communication abilities, leadership, time management, information administration, etc., are observed.

The student evaluation was designed from three aspects: the reviewer (the teacher or the student team), the population that defines whether evaluation is collective or individual and evaluation goal (What is evaluated? knowledge, skills . . .).

Table 1 shows the matrix used to design the assessment; this shows an example for a theoretical course. The matrix has the evaluation aspects and activities. This representation allows defining who, how, and what aspect is evaluated with each activity and its evaluation percentage. Also, it allows easily identifying whether the evaluation design is or not according to the regulations of the University. The faculty staff can incorporate different activities regarding the project; in the example shown in Table 1, the activities from b to g depend of the project work.

3.1 Peer-assessment activities

There are three peer-assessment activities, these are: peer-assessment on teamwork, written reports, and oral presentations. The last two activities correspond to the delivery of the project results and are developed at the end of each stage of the project, see Figure 3. The peer-assessment on Teamwork is applied at the end of the semester.

Public presentations and written reports evaluate knowledge and skills put into context and observe transversal skills. In each stage, the evaluation of oral presentations and written reports is done by the teacher and peers who receive the project (students who continue with the next stage of the project). The rotation of teams shown in Figure 2 is used to evaluate result deliveries of the project. The student team that finishes a stage is evaluated by a student team that continues the project. For example, in the first result delivery, *Team 2* evaluates *Team 1*. The rotation of the teams also allows for a team to be evaluated by a different team in each stage of the project and two teams are never evaluated by each other in the same stage.

To evaluate the public presentation and written reports, evaluation formats were designed. The evaluation of oral presentations is more focused on transversal skills, whereas the format for written reports is focused on both transversal skills and knowledge, since the information reported and the experimental data will be used to continue the project. In the formats, the queries are presented as statements and students evaluate the level of compliance of the statements. The used scale ranges from 1 to 5; 1 = no compliance and 5 = excellent level of compliance. Students use the same format to evaluate every oral presentation.

The oral presentation for each project stage is presented by a different member of the student team. Therefore, the number of team members cannot be greater than the number of project stages. The oral presentation is an individual evaluation; only the student who makes the oral presentation is evaluated. The oral presentation has two aims: to present the project advance and assess skills for an oral presentation (transversal skills). The time for oral presentation is 15 minutes, ten minutes to explain results and five minutes for questions. The team is free to choose the order in which its members will make oral presentations, but if the student chosen

Table 1: Example of an assessment matrix. Percentages correspond to a theoretical course. a = Quizzes, b = Written reports, c = Oral presentation, d = Exam on computer, e = Skills exam, f = Peer-assessment on Teamwork, and g = Self-assessment.

Aspects		**Evaluation Activities (%)**							TOTAL (%)	
		a	b	c	d	e	f	g		
Reviewers	Teacher	30	20	5	10	15			80	100
	Students		5	5			5	5	20	
Population	Collective		25						25	100
	Individual	30		10	10	15	5	5	75	
Goal	Knowledge	30	10						40	100
	Skills		15	10	10	15	5	5	60	

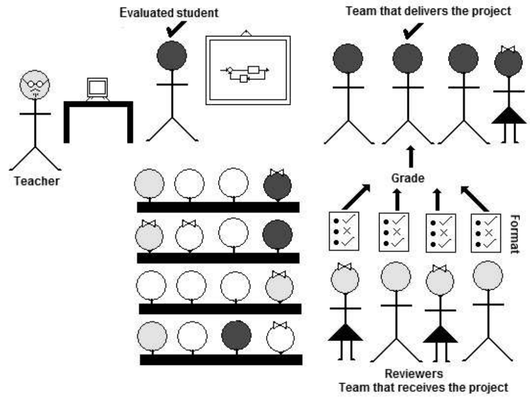
is not present, then another member of the team must carry out an oral presentation (every member of the team must be ready to make any oral presentation). Each member of the team that receives the project fills out a format; the final grade of the student speaker is an arithmetic average obtained from all the formats, see Figure 4(a).

For evaluating the written reports, the team that receives the project uses a format that has ten queries; four queries are kept for all deliveries; these queries aim to observe skills for written reports. The remaining queries change according to the project stage. Table 2 presents statements used to assess written reports at the second stage of the project in the first control course. Students must send written reports to the virtual campus before the public presentation so their peers and teachers can assess reports in advance. The grade of the written report is collective; the grade is for all the members of team that delivers the project and is concerted by all members of the team that receives the project, see Figure 4(b).

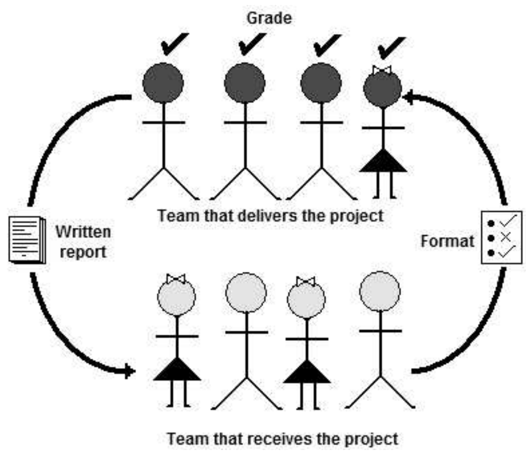
Formats for peer-assessment and self-assessment were also designed. In the peer-assessment on teamwork, teamwork skills are evaluated by co-workers in the project. Members of a team are evaluated by each other. Among other evaluated aspects are: compliance with assigned tasks, participation in team meetings and discussions, identification and solving of difficulties within the team and the contribution for the teamwork.

3.2 Self-assessment activity

The self-assessment is carried out at the end of the semester. This activity is used to gather students' opinions about their performance. Students reflect on the same aspects as Peer-assessment on teamwork. Other evaluated aspects are: use of schedule to be advised by teacher, self-learning and assistance in academic activities. The format is not focused on knowledge and scientific skills; it is focused on transversal



(a)



(b)

Figure 4: Peer-assessment for result delivery of a project stage. (a) Peer-assessment for oral presentation. (b) Peer-assessment for written reports.

Table 2: Peer-assessment Format for Written Reports .

Statement
1. The written report was done with the template defined for deliveries
2. The text was written concisely and clearly, and presents ideas consistently (logical order of ideas into paragraphs)
3. Tables and/or figures have relevant information for the subject developed; these synthesize, clarify, or explain the contents of the written report
4. References were cited according to template guidelines.
5. The report properly describes the methodology and procedures used to obtain the system model
6. In the report, students describe the experiments used to find the model parameters or the system model (e.g. via step test)
7. The state diagram for the linear-system model is properly obtained
8. The pulse transfer function is properly obtained
9. The report presents the validation results of the system model
10. Students achieve the objective set for this stage of the project

skills. The assigned percentage for self-assessment seeks to motivate students to think over aspects that are not usually dealt in technical courses like control courses but that are important in the professional performance.

3.3 Evaluation by teacher

Teachers evaluate oral presentations and written reports using the same formats used by students. Other activities presented in the evaluation matrix (See Table 1) that are evaluated by the teacher correspond to: quizzes, skills exam, and computer exam. Quizzes or short exams about specific topics are used to evaluate knowledge and scientific skills. These are scheduled at the beginning of semester and aim for a continuous evaluation of knowledge.

The computer exam seeks to observe technical skills or abilities using software for designing, analyzing, and processing data. The skills exam evaluates abilities to use plant prototypes and design and tune controllers; this activity is individual and it is carried out in the laboratory. The equipment available for this exam consists of a plant prototype, data acquisition system, computer with Matlab® and Labview®. The student must control a plant prototype using available resources. This activity is evaluated by teachers through a check list. In the laboratory course, check lists are also used to evaluate experimental skills in practices and training.

Table 3: Comparison between a LBL course a PBL Course.

LBL course	**PBL course**
Active Teaching	Active learning
Traditional lecture	Hands-On sessions
Individual work	Teamwork
Individual evaluation	Team evaluation
Assessment by teacher only	Self-assessment and peer assessment
Project at the end of semester as a evaluation activity	Project is developed throughout semester as central element of academic and evaluation activities
Exams focused on the theory	Evaluation is focused on knowledge and technical skills and on the observation of transversal skills

The student evaluation also promotes the development of transversal skills like self-confidence, criticism and self-criticism. Table 3 presents a comparison between main characteristics of a LBL course and a PBL course. The academic activities in the PBL courses are different from LBL courses; for example, the classical lecture is replaced mainly by Hands-On and tutoring sessions and the time distribution also changes significantly. In PBL courses, project spends 56% of the course time instead of 19% in the LBL courses, the time for individual work in PBL decreases, it corresponds to 8% compared to 31% in LBL courses; this means that the teamwork is more encouraged by the designed PBL approach.

4 IMPACT ASSESSMENT OF THE PROPOSED PBL APPROACH

4.1 Student Feedback

In evaluating the impact of PBL upon a control course, a survey was designed. In the survey, questions also are presented as statements. The surveys ask for three aspects: course methodology, teacher performance, and student performance. These aspects were respectively called: subject, teacher, and student. For the analysis of results, the statements were classified according to the four transversal skills that are the focus of this work. The survey is based on surveys from other universities that have implemented PBL

(Alcober et al., 2003), and the teacher evaluation format from Universidad del Valle.

The designed approach has been applied since the first semester of 2008. Results presented herein correspond to seven courses of Foundations of Linear-Control Systems; three courses used LBL (August to December, 2006; February to June and August to December, 2007, semesters) and other courses used PBL (February to June, 2008, August to December, 2008 and February to June, 2009, semesters). Two courses were developed simultaneously in the semester February to June, 2009. Table 4 has the score averages for transversal skills observed. Skills increase its averages for courses with PBL. In the courses with LBL, 68 students conducted the survey and 73 students did so in the courses with PBL.

Table 4: Skills Averages for Surveyed Courses. Observed transversal skills: Teamwork (TW), Problem Solving (PS), Self-Learning (SL) and Communication Abilities (CA).

	Semester	Student number	Skills average			
			TW	PS	SL	CA
LBL	August-December, 2006	27	3.2	3.3	3.8	2.8
	February-June, 2007	23	3.8	2.9	3.5	2.6
	August-December, 2007	18	3.9	3.6	4.3	3.6
PBL	February-June, 2008	34	4.3	4.0	4.3	3.9
	August-December, 2008	11	4.1	3.6	4.1	3.8
	February-June, 2009 (1)	16	4.4	4.2	4.4	3.9
	February-June, 2009 (2)	12	4.7	4.1	4.5	4.1

The reliability of the survey was evaluated by using the Alpha Cronbach Coefficient (Ledesma, 2004); each aspect was independently evaluated. The Alpha Cronbach coefficient is obtained by using Equation (1). Where k is the number of the survey items, S_i^2 is the item variance, and S_{sum}^2 is the total test variance. Coefficient values between 0.8 and 1.0 indicate a good reliability of the survey. The coefficient for the subject aspect was 0.927; for the teacher aspect, it was 0.942; and 0.875 for the student aspect.

Table 5: Student Survey Queries. QT = Queries related to Teamwork, QP = Queries related to Problem solving, QS = Queries related to Self-Learning and QC = Queries related to Communication abilities.

Statement
Subject aspect: *The course helps me to acquire:* QT1: Skills for working in a team QT2: Skills for working in interdisciplinary teams QP1: Capability to work per projects QP2: Capability to apply the knowledge in the practice QP3: Capability to solve engineering problems QP4: Ability and attitude to research QP5: Ability to manage information QP6: Capability to manage time QP7: Capability to adapt myself to new situations QP8: Quality compromise QP9: Attitude to develop actions for improving living conditions of the population QP10: The course includes activities that involve the economic analysis of solutions *The course helps me to acquire:* QS1: Capability for working by myself QC1: Capability to communicate effectively with others QC2: Capability to communicate with experts from other disciplines QC3: The course uses resources in a different language from the native language
Teacher aspect: QT3: The teacher timely orients my team in the solution of conflicts, problems, and difficulties QT4, QC4: The teacher encourages members of my team to improve and organize their presentations QP11: Teacher designs academic activities that stimulate my ability to analyze and solve problems QS2: Teacher orients students on how to choose and properly use learning resources
Student aspect: QT5: My contribution for the teamwork was good QT6: I participated actively in the team meetings QT7: I contributed in the team discussions QP12: I asked questions that encourage understanding of concepts QS3: I consulted extra bibliography and documentation by myself QS4: I was responsible with assigned tasks QC5: I paid attention to presentations by my class mates

$$\alpha = \left(\frac{k}{k-1}\right)\left(1 - \frac{\sum S_i^2}{S_{sum}^2}\right) \qquad (1)$$

The questionnaire statements are presented in Table 5. The analysis of the teacher aspect was done by answering the question: What kind of skill is developed in students as a result of the teacher action? The teacher competencies were not examined; therefore, the information is only concerned with the development of skills in students. In next subsections, the scores to survey queries given by students in LBL courses and in PBL courses are compared.

4.1.1 Survey results for Teamwork

Nine survey queries were formulated to evaluate the teamwork skills. The results obtained from the student surveys are shown in Figure 5.

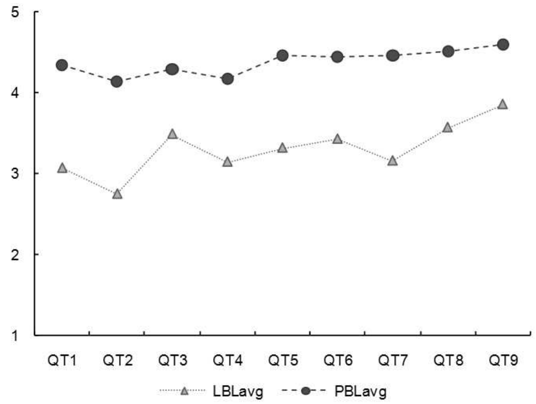


Figure 5: Teamwork in Project-Based Learning (PBL) courses vs. Lecture-Based Learning courses. The horizontal axis corresponds to the number of query. The scale used is from 1 to 5, 1 = no compliance and 5 = excellent level of compliance of the statement.

An improvement is observed with the PBL approach, the queries were graded with 4 and 5 compliance levels by most students showing better scores. While the average for queries QT1 and QT2 for LBL are 3.1 and 2.7, respectively, the averages for PBL are 4.3 and 4.1. According to the answers by students, PBL improves teamwork and interdisciplinary teamwork as compared to the LBL approach.

Students are more demanding with the teacher's work. Some students do not yet understand the new role of the teacher in PBL, this is normal when most courses in a curriculum use LBL approach because students are more familiarized with LBL teaching practices. The response averages for queries QT3 to QT9 are greater in PBL than in LBL courses. Queries QT5 and QT7 considerably increased their response averages; these results show major commitment by students with teamwork.

4.1.2 Survey results for Problem Solving

The survey considers 12 queries for the Problem Solving skill (see Table 5). In PBL courses, all queries obtained score averages greater than the score average for LBL courses (See Figure 6). An important increase is observed in queries QP1 and QP9. The query QP1 deals with the capability to work per projects and QP9 inquires on the attitude to develop actions addressed to population. The increase for the score average of response to the query QP9 is an important result because this query had never obtained a score greater than 2.3 in the LBL courses. Likewise, score averages for queries from QP4 to QP8 show that aspects like: attitude for research, time and information management, adaptation to a new situation and quality compromise are more encouraged from the PBL approach.

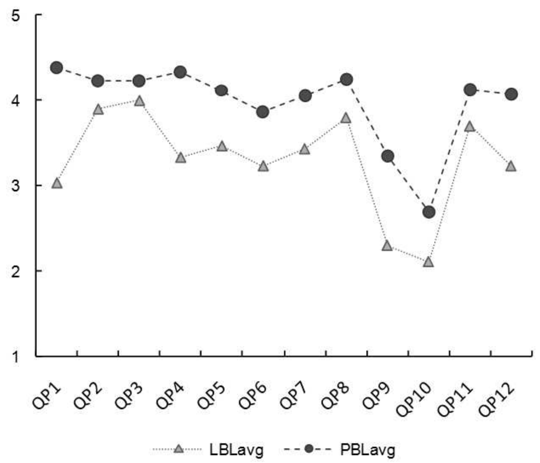


Figure 6: Problem Solving in Project-Based Learning (PBL) courses vs. Lecture-Based Learning courses. The horizontal axis corresponds to the number of query. The scale used is from 1 to 5, 1 = no compliance and 5 = excellent level of compliance of the statement.

In both PBL and LBL courses, students think they develop the capability to apply the knowledge to the practice (QP2) and solve engineering problems (QP3), and that the teacher stimulates them to analyze and solve problems (QP11).

According to the score for QP12, students think their questions were more effective for understanding concepts in PBL courses. Otherwise, the score of QP10 shows that it is a factor for improving, since its score, though greater in the PBL course, does not yet have an acceptable level of compliance.

4.1.3 Survey results for self-learning and communications abilities

In the self-learning skills, the survey explores the ability of students to work by themselves, QS1; teacher guidance about this, QS2; the autonomy in consulting extra bibliography and documents, QS3, and responsibility in the execution of assigned tasks, QS4. It is noted that in PBL courses all queries are graded over 4.0, (see Figure 7); however, the score for QS1 is just slightly greater than the score obtained for courses with LBL. One cause of such result can be attributed to many LBL courses using projects as evaluation activities at the end of the semester to observe the knowledge applied in practice and in these projects students work autonomously to achieve the project goals.

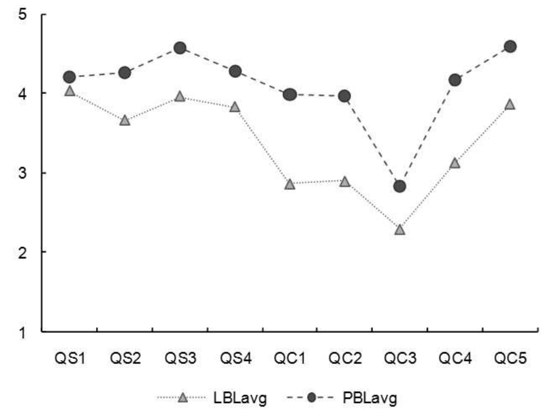


Figure 7: Self-Learning and Communication abilities in Project-Based Learning (PBL) courses vs. Lecture-Based Learning courses.The horizontal axis corresponds to the number of query. The scale used is from 1 to 5, 1 = no compliance and 5 = excellent level of compliance of the statement.

Regarding Communication skills, the survey has five queries and their score averages are greater for PBL courses, see Figure 7. In the case of the ability to communicate with others (QC1) and experts from other areas (QC2), the score average for courses with PBL is 4.0, much greater than that obtained by the LBL courses, which is 2.9. The query QC3 about the use of resources in a foreign language (English) also increased its score average from 2.0, in the courses with LBL, to 2.8 in courses with PBL; however, it is still considered an aspect for improving.

4.2 Student performance

This section presents a comparison between student performance in traditional education courses and the student performance in PBL control courses. This comparison is made on the final grades and allows readers to observe the advantages of the approach when it is applied in an actual case scenario.

The grades show that student performance also was impacted with PBL; for example, in Foundations of Linear-Control Systems courses, the percentage of students with

Table 6: Summary of Student Performance in the Second Control Course. **x** = total grade average of the course, σ = standard deviation, **SN** = Student Number, **SLP** = Student with low-performance, **VC** = variation coefficient.

	Semester	x	σ	SN	SLP	VC
LBL	Ag-Dic/06*	2.9	0.4	14	36%	14.88%
	Feb-Jun/07*	3.3	0.4	17	18%	13.51%
	Ag-Dic/07*	3.3	0.8	43	28%	24.27%
	Feb-Jun/08	3.7	0.7	32	3%	17.65%
PBL	Ag-Dic/08*	3.7	0.4	33	3%	10.51%
	Feb-Jun/09_G1	3.3	0.6	22	14%	17.35%
	Feb-Jun/09_G2	3.6	0.4	22	0%	10.60%
	Ag-Dic/09_G1*	3,7	0,4	19	0%	9.80%
	Ag-Dic/09_G2*	3,9	0,3	8	0%	6.58%

* Courses in which the student survey was applied

low academic performance was between 13% and 38% in LBL courses, whereas it was between 6% and 25% in PBL courses. Overall, 24% of the students had low academic performance in LBL courses and in the PBL courses, only 14% did so. Likewise, the general academic average was increased, it was 3.1 for course with LBL and 3.5 for courses with PBL (at Universidad del Valle, the minimum grade is 1 and the maximum is 5.0).

Table 6 has the final grade averages from nine courses of the second control level (Analysis and Compensation of Linear Systems), of which four ones used LBL and five ones were developed by using the designed PBL approach. According to results presented in Table 6, the overall grade-point average of students in courses of the second control level with LBL was 3.3, lower than the average obtained in the PBL courses that was 3.6.

Moreover, the percentage of students with low performance is less in PBL courses, this percentage ranged between 3% and 38% for LBL courses and it ranged between 3% and 14% for PBL courses. The overall percentage of students with poor performance was reduced from 17.57% with LBL to 10.96% in the courses with PBL.

The variation coefficients (VC), presented in Table 6, indicate that student performance is more homogenous in PBL courses and the distribution of the grades is in a higher rating. Figure 8 shows examples of grade distributions for courses of second control level, which were taught by the same teacher.

The first time courses were developed with PBL, the main difficulty was the high number of students, later the Electronics Engineering School of Universidad del Valle established a 20-student maximum per course, see Table 4. This was a good accomplishment for the approach because now students have more time to discuss the issues of their projects and

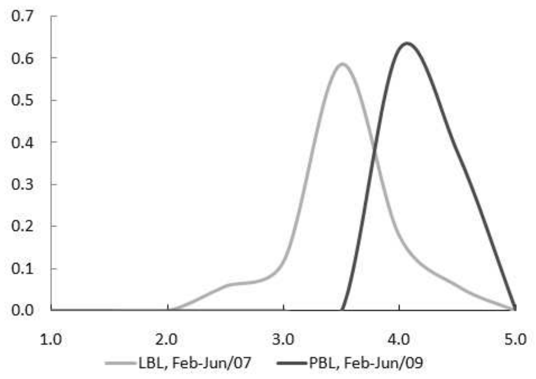


Figure 8: Examples of grade distribution for PBL courses Vs. LBL courses of Analysis and Compensation of Linear Systems I. The horizontal axis corresponds to the grade range and the vertical axis to normalized frequency in the range (0,1).

more following up by teachers. However, a greater workload of teachers was required, this is typical behavior when a new approach is implemented, but now the teacher workload is similar to traditional education, due mainly to the use of the virtual campus for several evaluation activities. So far, the use of this PBL approach has not decreased the time commitment of teachers, but has improved student performance, which is another way of looking at the approach efficiency.

This paper shows a proposal for control education that encourages the development of transversal skills, needed to face the new challenges of engineering, from technical courses. GICI hopes that information exposed helps other teachers to design their own PBL approaches according to their context and university policy.

5 CONCLUDING REMARKS

The design of this Project-Based Learning approach for control system courses takes into account aspects like: problem definition, project development, student teams, support resources, and student evaluation. Students are engaged in project work that seeks to solve a control problem, thus they learn topics while developing the project. The PBL approach evaluation is carried out observing transversal skills. This work seeks to encourage PBL implementation in Engineering Education, showing a PBL experience developed within a curriculum that uses Traditional Education.

The survey results show that, in PBL courses, students graded with greater scores statements related to transversal skills that are the scope of this work. Now, students are more organized and engaged in their work. They defined the necessary tasks and resources to develop each stage of the project, for example; they organized meetings with their coworkers, consulted experts from other areas outside the university and sought extra bibliography, and carried out technical visits to factories. Also, the student's grades show that, in general, student performance is better with PBL.

Students have an active role in evaluating their classmates. They carefully review public presentations and written reports since results presented in these assignments have necessary information for continuing to the next stage of the project. Furthermore, the evaluation design emphasizes in the criticism and self-criticism through self- and peer-assessment activities.

The planning of learning activities and the selection of support resources are very important in the implementation of the proposed PBL approach because these guide the learning of topics, laboratory practices, development of skills, and define the learning environments.

Because the linear-control-system courses are unique in a curriculum that uses PBL, the main difficulties in applying PBL in control courses are the inertia brought in by students from traditional teaching and resistance to change along with mistakes in using support resources.

The Industrial Control Research Group (GICI) at Universidad del Valle is developing a complete curriculum for the control area and designing new web-based support resources for remote experimentation, as well as for defining problems and managing projects in the PBL approach. Also, it is designing new games for Hands-On activities, which seeks to help students to learn concepts through playing. GICI has considered as future research topics on PBL practice: the role of the teacher, effectiveness of PBL in the development of transversal skills, PBL learning environment and resources, and comparison of PBL approaches in control systems. Moreover, GICI is working to integrate the proposed PBL approach in other courses of the Electronics Engineering Program like: circuits, signal processing, measurement and instrumentation, electronics, etc.

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