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Comparison of PBL Curricula within Control Engineering Education*

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During the last twenty years, various forms of PBL have been implemented in diverse educational programs and national policy regulations, and to different extents, ranging from a single course level to an integrated PBL curriculum. This has resulted in a variety of PBL curriculum practices. In this article, a comparison of two PBL cases will be described in order to study the advantages and disadvantages of the two systems. One case presents a single level comprised of two courses and the other one is an integrated PBL curriculum, and both are focused on control engineering courses. The PBL approaches are compared based on an analysis of the study guidelines, the technical curriculum, the themes of the project, the project introduction and specification given by staff, as well as student outcomes in the form of technical skills and skills related to specification requirements, project organization and structuring based on a study of written project proposals and student reports delivered. The results show that both the PBL curricula formulated the same technical learning outcomes, modeling and control methods; however, in the curriculum practice there are differences related to the scope of curriculum objectives, knowledge, independence of the student work, supervision management, and students' preconditions related to PBL.

Keywords: PBL Project Based Learning; Control Engineering Education

1. Introduction

The PBL acronym can mean Problem-Based Learning, but it can also mean Project-Based Learning and in this article we refer to PBL as the combination of the two curriculum models. Twenty years ago, there were basically two different models: the Problem-Based Learning model practised especially in medical education at Maastricht University and McMaster University, and the problem-oriented project work model that was practised at Aalborg University and Roskilde University, Denmark and has become known as the engineering project model or the Danish model [1]. Today, the picture is much more complex as institutions worldwide implement elements from both the medicine model and the an engineering models, and the utilization of PBL takes place both in single courses and at a more integrated curriculum or system level.

Therefore, it is also interesting to compare the existing PBL practices to study the advantages and disadvantages, as it is quite resource-intensive to transfer the entire curriculum to PBL and demands a whole institutional change, whereas it is easier and more flexible in a traditional university to change a single course. But, are the intended learning outcomes and practices similar in both approaches? We have chosen to study the Control Engineering curriculum at Aalborg University, Denmark and the curriculum at Universidad del Valle, Colombia. Both universities have a bachelor program in electronic engineering with a control engineering specialization—Aalborg University has an integrated curriculum, whereas Universidad del Valle has a specific area of the curriculum. In this article, we want to compare these two curriculum approaches based on a study of written reports of projects delivered by students, the technical curriculum, problem definition, themes of the project, project progression, and the intended student learning outcomes. The comparison of approaches allows us to observe the advantages and limitations of using PBL in a single course or as an educational approach in an integrated curriculum from information on a specific area.

2. Model for analyzing PBL curriculum

De Graaff and Kolmos [2] have formulated a series of learning principles to focus on the similarities in the health PBL model and the Danish PBL models. These learning principles are formulated in three approaches:

- The cognitive **learning approach** means that *learning is organized around problems* and will be *carried out in projects.* It is a central principle

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for the development of motivation. A problem (an inquiry, an anomaly, contradiction, need, etc.) sets the starting point for the learning processes, places learning *within context*, and bases learning on the learner's experience. The fact that it is also *project-based* means that it is a unique task involving more complex problem analyses and problem-solving strategies and that there is a timeframe to consider, such as a deadline.

- The **contents approach** especially concerns *interdisciplinary learning*, which may span across traditional subject-related boundaries and methods. It is an *exemplary practice* in the sense that the learning outcome is exemplary to the overall objectives of the curriculum. Normally, the problem approach supports the relationship between *theory* and *practice* in that the learning process involves an analytical approach by using theory in the analysis of problems and problem-solving methods. Furthermore, this is training in *research* methodologies.
- The **social approach** is team-based learning. The *team-learning* aspect underpins the learning process as a social act where learning takes place through dialogue and communication. Furthermore, the students are not only learning from each other, but they also learn to share knowledge and organize by themselves the collaborative learning process. The social approach also covers the concept of *participant-directed learning,* indicating collective ownership of the learning process and, especially, the formulation of the problem.

Defining PBL as learning principles allows varying the development of PBL models and permits adjustment flexibility at the institutional level. However, there is no logical deduction from the learning principles to the curriculum level—on the contrary, history shows that the models have been developed by ideas, trial and error, theoretical understanding and new experiments, [1]. Therefore, formulation of core-learning principles can only be used as relative bearing points and there is need for more concrete analytical models for the curriculum level.

Inspired by the five models proposed by Savin-Baden [3], Kolmos et al. have developed the following model for the elements that must be aligned in a problem and project-based curriculum. The model has been developed with reference to the curriculum principles of alignment [4], PBL models [5–9], and curriculum studies [10].

Kolmos et al. [3] have identified the following seven elements: objectives and knowledge, types of problems and projects, progression and size, student learning, academic staff and facilitation, space and organization and, finally, assessment and evaluation. All these elements are elementary in a curriculum and all elements must be aligned with each other.

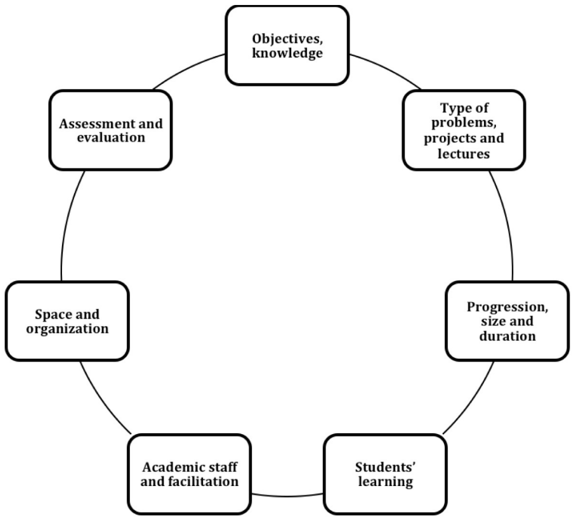

Fig. 1. PBL Alignment of elements in the curriculum.

The alignment principle is based on a holistic understanding. If there is a change in one element it will effect change in all the other elements as well. However, based on the five models by Savin-Baden, there will be dimensions for each of these elements. The extremes in each dimension represent, on the one hand a more teacher- and discipline-controlled approach to PBL where knowledge acquisition is core, and on the other hand a more innovative and learner-centred approach based more on learning seen as construction of knowledge.

PBL dimensions are described in Table 1. The left side of the list expresses the teacher-controlled approach, while the right side represents open-problem based and learner-centered approach. There are many points in between these extremes and the model does not seek to describe a detailed reality—but merely to point out the possibilities for variation.

The poles for each dimension also have to be aligned. The learning process will be complicated if the learning objectives are formulated as more traditional disciplines and, on the other hand, students are encouraged to go for ill-defined problems.

Taking into account the characteristics of the PBL approaches used in control engineering at Aalborg University and Universidad del Valle, this article will use the 'PBL Alignment of elements in the curriculum' presented in Fig. 1 to compare the PBL approaches from dimensions such as objectives, problems and projects, progression, student learning, staff and facilitation, space and organiza-

Table 1. Dimensions of PBL curriculum elements [3]

Curriculum elements	Discipline and teacher controlled approach	Innovative and learner-centred approach
Objectives and Knowledge	Traditional disciplines objectives Disciplinary knowledge	PBL and methodological objectives Interdisciplinary knowledge
Type of problems and projects	Narrow Well-defined problems Disciplined projects Study projects Lectures determine the project	Open Ill-defined problems Problem projects Innovation projects Lectures support the project
Progression, size and duration	No visible progression Minor part of the curriculum	Visible and clear progression Major part of course/curriculum
Students' learning	No supporting courses Acquisition of knowledge Collaboration for individual learning	Supporting courses Construction of knowledge Collaboration for innovation
Academic staff and Facilitation	No training Teacher-controlled supervision	Training courses Facilitator/process guide
Space and Organisation	Traditional library structure Lecture rooms	Library to support PBL Physical space to facilitate teamwork
Assessment and Evaluation	Individual assessment Summative course evaluation	Group assessment Formative evaluation

tion, and student assessment. These dimensions can be easily identified in each approach, which allows knowing the differences and similarities of both PBL experiences.

2.1 PBL approaches and methods

2.1.1 PBL approach for linear control systems at Electronics Engineering at Universidad del Valle, Colombia (Univalle PBL approach)

This Project-Based Learning (PBL) approach was designed for the control area of Electronics Engineering at Universidad del Valle [11]. This area includes two levels, each has a theoretical course with three academic credits and a laboratory course with one academic credit (one academic credit = 48 working hours) and is developed in 16-week periods (one semester). The PBL approach integrates both the theoretical course and the laboratory course as a single course; however, these courses are evaluated separately. The first level of control area corresponds to Foundations of Linear Control Systems and the second one corresponds to Analysis and Compensation of Linear Systems. In both levels, topics on analogue and digital control are studied simultaneously in the state space and transfer function representation. These courses are developed in the third year of the engineering program.

Other control courses are offered as elective courses in the fourth and fifth years. These courses include topics like: identification and modeling of systems, multivariable control, robust control, nonlinear control, industrial process control, and automation projects. The PBL approach has been applied only in the compulsory courses of the control area.

2.2 Bachelor of Electronics Engineering, Control Engineering, Aalborg University (Aalborg PBL model)

Control Engineering is a one-semester specialization at the Bachelor of Electronics Engineering program at Aalborg University. The Bachelor program lasts 3 years/6 semesters. One semester is 30 ECTS and each ECTS equals 30 hours. It includes project work and courses. Problem-based learning through project work is seen as the most important part of education at all levels and covers more than half of the study time during each semester.

The curriculum for a semester is described in the study guidelines. This description covers a number of courses, as well as the theme and learning objectives for the project work. During the semester, students follow a number of courses, determined at the beginning of the semester.

2.2.1 Methods

The PBL curriculum model has been the analytical framework for the collection of data from the two cases. In this article, the first data presents the comparative study of the two models by comparing the official curriculum and analyzing students' project reports. The authors from the two universities collected data partly by reading the various curriculum descriptions, partly by interviewing staff and students. The data were analyzed and compared. Furthermore, reports from 5 student groups (20 students) from the Univalle University and reports from 8 student groups (41 students) from Aalborg University were analyzed and compared.

There have been some difficulties in the analysis of the work as the Colombia case only has student reports in Spanish and, therefore, the analysis of these reports was done from numeric and graphic data of project results.

3. Comparison of two PBL models

3.1 Objectives and knowledge

The objectives of the Univalle PBL approach are:

- To analyze analogical and discrete linear control systems in the time and frequency domain, with input-output or space-state representation, taking as examples electrical, mechanical, thermal, flow, and level systems.
- To design PID and RST controllers by using pole-location, root-locus analysis, and frequency response.
- To design controllers and/or observers of state for systems described by state-variable models.

These objectives are distributed in the two levels. For the first level, the objectives are: To describe the main elements and signs of a typical control loop, describing systems by using block, flow, and state-space diagrams; To obtain the mathematical model of a control system in transfer function and state-space variables; to analyze control systems in the time domain and effects of feedback in the system operation and experimentally tuning PID controllers.

For the second level of the control area, the objectives are: To analyze linear control systems by using root-locus analysis and frequency response (Nyquist and Bode), to design controllers by using root locus and frequency response; to describe the advance control structures like cascade control and feed-forward control; to analyze the properties of stability, controllability, and observability of a system; to design controllers and/or state observers for systems described by state variables.

For the PBL approach, development of transversal skills like teamwork, self-learning, communication abilities, and problem solving was included as an objective of the course.

The objectives of the Aalborg PBL model are:

- To ensure the study guidelines of the subject matter of the project work specify a theme, a set of objectives, and the content of the problem to be solved within the project. The theme for the project during the 6^{th} semester is Control Engineering. According to the study guidelines, the objectives for the project described by Bloom's taxonomy [12] are:
  - To analyze a dynamic system in time and frequency
  - To apply classical control methods for feedback design
  - To apply model-based methods such as state space control and pole placement for controller design
  - To apply mechanical, thermodynamic, or biological equations for development of dynamic models
  - To analyze and apply different methods for simulation of dynamic systems
  - To obtain application level in implementation and test of models and controllers
  - To understand industrial control and principles for supervision in control systems

3.2 Types of problems, projects, and lectures

In the Univalle PBL approach, the problem is defined by the teaching staff by taking into account three elements: a context, a variable, and a control target. The problems can be for: the local context, in the control of a variable of regional industry, and the control of a laboratory prototype. Some benchmarks also are used.

Local context problems look for students to understand and reflect on their immediate environment. This aspect is important because industries become resources of approach and students can easily establish contacts with the factories. Contexts are chosen according to the common industries in the region where Universidad del Valle is located. The context is a reference for solving the problems, but these are not directly solved in the industry.

An example of problems of context is: '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. A control system is designed to keep the pH concentration of the sugar cane juices near 7. In this example, the variable is pH concentration; the control objective is 'to control the pH concentration of sugar cane juices,' and the context is the sugar-cane factory.

The kind of problem defines experimental constraints; for example, the problems of context and benchmarks are solved by using mathematical models; in this instance, students carry out the experimentation on a computational platform in real time, and the hardware in the loop can be connected with the platform. This platform is also used to test the control strategies before implementation on the prototype.

To solve the problem a project is developed throughout the semester. The project is the central element in the approach because academic and evaluation activities are scheduled according to it. This PBL approach considers four stages for developing the project at each level; each stage corresponds to both a thematic focus and one or two objectives of the course (Fig. 2).

In the lecture sessions, the teacher aims for hands-on activities so that students learn new topics. These

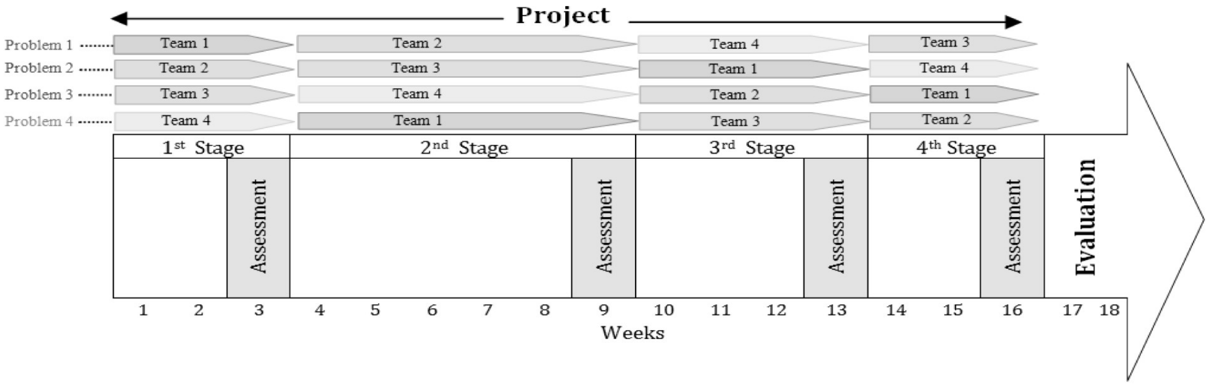

Fig. 2. PBL Approach for Linear Control System Area in Electronics Engineering at Universidad del Valle, Colombia. Project stages correspond to the first level of control.

activities are designed by the teacher. Students receive a guideline to develop the activity; once the students finish it, the teacher leads a brainstorm session and, finally, the teacher develops a short lecture on the topic. Hands-on activities aim for students to actively participate in the lecture and learn the topics in a fun way [13].

In the Aalborg PBL model, the contents of the project during the control semester are described in the study guidance as follows:

> The project is based on the problem of controlling a physical system. The system can be mechanical, thermal, electrical, biological, or chemical in nature. A dynamic model of the system has to be derived. The model has to be adjusted and verified by measurements on the system. Sensor and actuator characteristics are handled as a part of the adjustment procedure. Demands on the dynamic behavior of the system are formulated as time and frequency responses. Based on the dynamics of model, a classic and a state space controller are designed. The control strategies have to be investigated by dynamic simulation. The control systems have to be implemented and tested against the specified demands.

The projects are defined from the description of project objectives and content. Students can find their own project or they can choose from proposals furnished by the supervisors during the semester. Projects can be industrial systems or physical laboratory models of industrial systems.

Examples of student projects during the control semester are to design control systems for a gantry crane, a Segway, a marine boiler, the attitude of an ADCS satellite, or a heating and ventilation system. In the project, students must manage all aspects of control system development.

During the semester, students follow a number of courses determined at the beginning of the semester. One course ECTS is normally five four-hour units. Each unit consists of a lecture and some exercises; the exercises are solved within the groups, and the lecture offers assistance. Exercises can be short delimited tasks closely related to the lecture of the day or they can be mini-projects covering all aspects of the course. Courses can be closely related to the objectives of the project work (PE) or they can be of a more general nature (SE).

During the 6^{th} semester, courses are given within the following areas:

Matrix Computations: Theory and Numerical Methods	2 ECTS	(SE)
Introduction to Information Theory	1 ECTS	(SE)
The Origin and Registration of Signals	1 ECTS	(SE)
Modern Control Theory	2 ECTS	(PE)
Frequency Response Design of Control Systems	1 ECTS	(PE)
Modelling and Simulation	3 ECTS	(PE)
Scientific Methods	2 ECTS	(SE)

3.3 Progression, size, and duration

In the Univalle PBL approach, the project is developed in stages during two semesters in 16-week periods. Students spend 108 working hours per semester on the project. The duration of each project stage is different; its execution time depends on the objectives and the complexity of tasks that students must develop to achieve them. For example, in the Foundations of Linear Control Systems, the project is developed as follows: in the first stage (3 weeks), students describe physical systems by identifying elements of a typical control loop; in the second stage (6 weeks), they obtain a system model; in the third stage (4 weeks), they discuss the time response of the system; and in the last stage (3 weeks), they implement a PID controller in their projects.

The projects are developed by teams of three or four students. Each student team participates in the development of different projects, which are carried out in four stages (Fig. 2). This allows students to know different contexts, industrial variables, and use diverse experimental resources—it is usual in real life for projects to be developed by several teams. To establish homogeneity among teams, these are conformed according to student grade-point averages; students with high averages are grouped with students with low averages. The rotation of the problems among teams also allows definition of peer-assessment activities. For this reason, student teams are comprised of a number of members less than or equal to the number of project stages.

In this PBL approach, students spend most of their working time on the project; 56% of the time is for the project, 13% for the lectures, and the rest of time is for lab training and evaluation activities.

In the Aalborg PBL model, before the semester the students obtain knowledge on analogue and digital electronics, microcontrollers, software development and analysis, real-time systems, modeling, and design of electrical systems. The topics include basic knowledge on feedback in electronic circuits and basic modeling of dynamic systems.

The control semester is the last semester in the Bachelor education and all semesters are equally focused on project work.

The curriculum becomes more and more complex and interdisciplinary during the study. The semester in focus demands a project combining the skills from previous semesters and modeling, simulation, and control of dynamic systems.

During the control semester, the project work covers 18 ECTS, corresponding to 540 hours including examinations.

3.4 Student learning

In the Univalle PBL approach, there are two kinds of learning outcomes. The first concerns control learning and the second is about the transversal skills. In turn, the outcomes of controlled learning are distributed in the two levels of the control area, as follows:

In the first level, students describe the components of the system, sensors, actuators, and plant; they represent the system by using ISA standards and analyze the context where the system is. Next, students obtain the model of the system; in this instance, they apply knowledge about transfer functions and state space; they also use experimental methods like the step test. The model of the systems is simulated in real time on a platform and analyzed in the time domain. At the end of the first course, students tune PID controllers. These controllers are connected either with the prototype plant or the model in the platform through a data acquisition system. Students also use real-time simulation to test controllers before their implementation in the real system.

The second level is devoted to analyzing the system in the frequency domain, stability, and the design of control strategies. Most of the projects developed in the first control level are continued in the second level. Students analyze the system model in the frequency domain and via root-locus analysis; sometimes they obtain the frequency response and root locus directly from prototype plants via experimental tests. After that, students design analogical controllers by using the frequency response, root locus, and pole-location; these controllers are tested in the real-time simulation platform. Control structures like cascade control and feed-forward control are studied. Finally, both digital PID and space state controllers are designed. Usually, observers are also designed for the space state controllers. At the end of the course, students can compare different control strategies, along with their advantages and disadvantages.

Regarding transversal skills, the PBL approach was designed to promote teamwork, self-learning, problem-solving, and communication abilities. Additionally, other skills like decision-making, time-management, and information administration are encouraged with project work. Students are free to organize the work, define the role for each team member, assign tasks, and supervise the progress of the tasks assigned.

In the Aalborg PBL model, student learning is a comprehensive mix between technical learning and process skills such as project management and collaboration related to the PBL approach. The technical learning is defined in the learning objectives for the specific semester, whereas process skills are defined at a more general curriculum level. For most projects, the physical system is present at the start of the project, otherwise it has to be designed and constructed by the students with help from the supervisor and technicians. Given the physical system, students have to describe the system including characteristics such as dimensions, equipment, etc. The development environment has to be established and documented; this part will typically include the computer system, data acquisition, the data transmission system, amplifiers, filters, and wiring among others. An embedded system able to handle real-time control must be established.

The next part of the project is to derive a non-linear dynamic model of the system describing the input-output relations of the system. This part includes model structure determination, derivation of dynamic equations, parameter estimation, and model validation. The non-linear model is used for a real-time simulator for controller tests. Based on the model and system knowledge, students formulate demands for the control system.

The non-linear model is linearized and used for control system design. First, a classic design method is used. The control system structure typically ends up with independent loops, some with inner loops. The design could be done via, for example, Bode, Nyquist or root-locus methods. The controllers are tested on the real-time simulator before implementation on the physical system.

A state space model is developed and a state space controller is designed; this controller will typically include an observer. This controller is tested on the real-time simulator, adjusted and implemented. Acceptance tests of the controllers are carried out and the results are compared based on system demands.

In addition to the technical skills, the project work implies that the students develop skills within collaboration, communication and project management as four to six individual students are working together in the project groups. To meet project demands, it is necessary for students to achieve an overview and to be able to structure large and complex tasks. The overall project problem must be separated into sub-problems with well-defined interface and coordination. Subtasks must be distributed among group participants and, at the same time, all group members must be aware of all decentralized solutions. Iterative adjustment of the overall plan and subtask division is carried out during the semester. These skills are developed by project work in six semesters. The increasing complexity of the projects implies that the demands within collaboration and organization rise during the time at the university.

The project work is then reported in a report typically of 150 pages in Danish or English. The results are presented orally prior to the examination.

3.5 Academic staff and facilitation

In the Univalle PBL approach, the teaching staff is comprised of two teachers for each level, one for theory and the other for laboratory work. Taking into account that problems are defined in diverse contexts and their solutions require knowledge from different areas, each student team has an expert on the issues of the problem who is not a teacher of the course but has recognized expertise on the problem topics. The expert is invited by teachers to participate in the course as an advisor for developing the project and is consulted by students on specifics topics related to the problem and its solution; the expert does not orient the project but supports its development. Participation by 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 such as identification systems and normative standards. The curriculum of the control area and the development of courses are supported by members from the Industrial Control Research Group; this group has eight professors and five assistant professors.

Aalborg University has been using the PBL approach since 1974, implying that in-house staff are very familiar with the Aalborg model of project work and connected supervisor tasks. It is mandatory for new academic staff to participate in pedagogical workshops training supervision of project work and introducing the entire PBL philosophy. Supervisors are assistant professors, associate professors, or full professors.

Given that the staffing level in the laboratory is limited, students must be capable of independently solving most technical problems related to the equipment.

3.6 Space and organization

In the Univalle PBL approach, to develop project activities, students take advantage of available spaces in the University. The University has spaces like study rooms at the library, study halls in the buildings of the Electrical and Electronics Engineering School, lab rooms with computers, boards, specialized software, and access to real simulation tools and informatics rooms, among others. These settings are used by students; they define where to hold their meetings. Most project activities are conducted in the automation laboratory. Also, students schedule meetings in their homes or distribute tasks to be developed individually by team members. The University does not have group rooms for teams.

In the Electronics Engineering program at Aalborg University, the control engineering specialization semester consists of 11 ECTS of courses and 19 ECTS of project work.

During the 6^{th} semester, there is a maximum of 4-6 members in a group. Each group has its own room for project work and course exercises. There are lab facilities for the project work or students have direct access to industrial equipment in associate companies. Groups are guided by a supervisor during the project work. Typically, the group and the supervisor have one meeting per week to discuss the progress and problems in the project. Prior to these meetings, students formulate an agenda with problems they want to discuss and they hand in initial sections for the final report for discussion.

The university provides a room for each group and laboratory facilities for the project. Laboratory facilities will typically include the physical system to be controlled, necessary equipment like computers, sensors, amplifiers, etc. A small amount of money will be available for each project for necessary purchases. In some projects, students have direct access to industrial equipment in associate companies.

3.7 Assessment

3.7.1 Student assessment in the Univalle PBL approach

The design of the assessment considers all dimensions of evaluation: self-assessment, peer-assessment, and teacher-assessment. The student evaluation is designed from three aspects: the reviewer (the teacher or the student team), the population that defines whether the evaluation is collective or individual and the evaluation goal (what is being evaluated? knowledge, skills. . .) [14].

Table 2 shows an example of the matrix used to design the assessment in the theoretical course. The matrix has evaluation aspects and activities. The teaching staff chooses different activities regarding the project; in the example shown in Table 2, five activities depend on the project (activities from b to g). These activities correspond to 65% of the evaluation.

The self-assessment activity is carried out using a form at the end of the semester; the percentage mark for this activity seeks to motive students to reflect on their performance and development skills.

One of the most important aspects of the evaluation design for this PBL approach is peer-assessment activities. These are related to the development of the project, correspond to results delivery, and are conducted at the end of every stage (Fig. 2). The members of the team that receive the project evaluate the performance of their peers through forms designed specifically for this task.

Results delivery includes oral presentations and written reports. The oral presentation seeks to assess the communication skills of students making the presentation and it is an individual evaluation in which the grade is only for the student speaker (Table 2). Each team member must carry out at least one oral presentation; for this reason, the number of team members is less than or equal to the number of stages of the project. The team is free to choose the order in which its members make the presentations. Each member of the team that receives the project fills in a form; the final grade of the student speaker is the average of the grades from different forms.

Written reports are also evaluated by the team receiving the project. This evaluation activity aims to assess the ability to write technical reports and specific outcomes that should be delivered according to the project stage ending. The grade of the written report is collective, *i.e.*, it is agreed by members of the team receiving it, and it is recorded for each member of the team delivering the project. The rotation of equipment, presented in Fig. 2 allows for a team to be evaluated by a different team at each stage of the project and for two teams never to be evaluated by each other within the same stage. The teachers also evaluate results delivery; they use the same forms as the students.

Other evaluation activities are quizzes, a computer-based exam, and a skills exam. The quizzes or short exams on specific topics are used to evaluate knowledge and scientific skills and are scheduled from the beginning of the semester. These are intended for continuous evaluation of knowledge. The exam on a computer seeks to observe technical skills or abilities to use software for designing, analyzing, and processing data. Finally, the skills exam evaluates abilities to use plant prototypes and design and tune controllers.

3.7.2 Assessment in the Aalborg PBL model

The assessment takes part as a two stage procedure: first a common oral presentation of the report and secondly an individual oral assessment of the entire work. The oral presentation often includes a laboratory demonstration of the results of the work. In the individual part of the assessment students are asked questions one by one randomly on the content of the entire project report. An external examiner is present at the assessment and the students are individually graded according to the 7-point grading scale. They are required to pass the project examination to be allowed to continue on to the next semester.

Table 2. Example of an assessment matrix. Percentages correspond to a theoretical course

		Evaluation Activities (%)								
Aspects		**a**	**b**	**c**	**d**	**e**	**f**	**g**	**Total (%)**	
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	

a = Quizzes; b = Written reports; c = Oral presentation; d = Exam on computer; e = Skills exam; f = Peer-assessment on Teamwork; and g = Self-assessment.

The general courses (SE) are examined separately. The PE courses are examined as a part of the project.

3.8 Summary of comparisons

The Aalborg PBL model is an educational model in all the curricular and organizational levels of the University. The Univalle PBL approach is only a curricular level constrained to the specific area of control systems: only the control courses use PBL and the rest use traditional education. This difference implies different support resources and organization of the programs. The comparison of models is summarized in Table 3.

4. Discussion

Two PBL modeling and control approaches are compared. The comparison is based on an analysis of the study guidelines, the technical curriculum, the themes of the project, the project introduction and specification given by staff. The student outcomes in the form of technical skills and skills related to specification requirement, project organization and project structuring are evaluated based on a study of written project proposals. As a framework for the comparative analysis, the PBL curriculum model is used [3].

4.1 Objectives and knowledge

Both models have similar topics and objectives. Topics like time response, frequency response, root-locus analysis, classical control methods, state space control, and pole placement for controller design are dealt with by both models. However, control education at Aalborg University deals with topics beginning with the modeling of nonlinear systems, whereas the control courses at Universidad del Valle consider typical nonlinearities of actuators like dead zone and saturation, but the subject centers on linear systems. Furthermore, the Aalborg University curriculum also has broader objectives such as problem analysis, problem-solving methodologies and process skills.

Table 3. Summary of PBL model comparison

Element	**Aalborg PBL Model** Educational model	**Univalle PBL Approach** Approach in specific area of curriculum.
Objectives and Knowledge	Analysis and control design for linear systems. Subject involves non-linear control system modeling.	Analysis and control design for linear systems. Subject does not involve non-linear control system modeling. This topic is dealt with in an elective course.
Problem, Projects, and Lecture	Problems from real context where students have to analyze and define the problems. It is possible to apply the solution in the real context. Involves 3 courses of 6 ECTS+18ECTS of project work.	Problems from real context defined by teacher. The context is used only as reference for the solution. Involves 2 theoretical-practical courses of 12.8 ECTS. Uses hands-on activities in lectures.
Progression, size, and duration	One semester with 540 working hours dedicated to the project.	Two semesters, each semester with 108 working hours dedicated to the project.
Student Learning	Problem solution covering all aspects of a practical control problem. Skills related to specification requirement, choice of method, specification and construction of lab equipment, interfacing, implementation, test and project management, organization and coordination. Documentation and evaluation of methods and results.	Problem solution as the sum of contributions made by several teams. Introduction to project work to promote teamwork, self-learning, problem solving, and communication abilities. Report on progress reports.
Academic Staff and facilitation	Besides platforms and prototype plants, students can have access to industrial equipment in associate companies. Academic supervisor for project work for each team.	Project carried out on emulation platforms and pilot and prototype plants. Expert for each problem.
Space and Organization	Group room and lab facilities.	Approach uses spaces from traditional education.
Assessment and Evaluation	Individual oral assessment by external examiner. Written report like a thesis document at the end of the semester. Oral presentation of project results.	Individual and group evaluation by teaching staff. Peer-assessment and self-assessment are also used. Written report like an article at the end of each project stage. Oral presentation of project results.

4.2 Types of problems, projects, and lecture

Though both approaches look for students to solve a problem defined in a real context, there are different constraints for the project. The project chosen in the Aalborg PBL model can be developed in the real context. The Univalle PBL approach uses the context only as a reference to obtain information about the problem, but the problem is not solved directly there. This is solved in the pilot and prototype plants or by using a model on an emulation platform. Nevertheless, solutions proposed for problems in both models are coherent with constraints defined by them.

In the Aalborg PBL model, a student team develops a project from beginning to end. In the Univalle PBL approach, a project is carried out in stages by different teams; thus, a team participates in the development of at least four projects, which allows them to know different contexts.

The Univalle PBL approach uses hands-on activities to introduce topics seeking to encourage learning in a fun way.

4.3 Progression, size, and duration

The duration and progression of the project is different in both approaches. In the Aalborg model, the project is carried out throughout one semester and in the Univalle model the project is developed in stages during two semesters. In Aalborg, the project corresponds to 18 out of 30 ECTS per semester. In other words, the project corresponds to 60% (540 working hours) of the working time per semester. The project is completely developed in one semester and the students take 6 ECTS in courses related to the project. In Universidad del Valle, the working time of the project corresponds only to four academic credits of 20 academic credits scheduled per semester (in Colombia, one academic credit = 48 working hours). This indicates that students spend 20% of their working time (192 working hours) per semester on the control course, of which 108 working hours are spent on the project; therefore, the project is developed in two semesters spending a total of 216 working hours in its execution. Moreover, students take courses from other areas during the same semester.

4.4 Student learning

For this aspect, a comparison is made of the learning outcomes by observing the written reports of the projects.

As observed above, most topics and tasks are common in both models. However, there are marked differences between the models regarding the results obtained. The Aalborg PBL model takes into account the solution of the project as an integral proposal given by one team, which is described in a report, whereas the Univalle PBL approach emphasizes the solution as the sum of contributions made by several teams, which are presented in short reports.

There are some differences in initial conditions and constraints of the project. For example, while the project in the Aalborg PBL model begins from the non-linear system model and students must linearize the model, in the Univalle PBL approach, courses focus on linear systems, and students develop the project from the linear model by taking into account nonlinearities of actuators like dead zone and saturation. This difference implies that control students in Aalborg University can go more deeply into the modeling of non-linear systems as part of a larger problem. Likewise, the expected results of the project are also different.

Both models encourage the use of simulation tools to analyze system dynamics and test control strategies. Real-time simulations executed via Simulink from Matlab® software are used to know the performance of a controller before its implementation in real systems.

In the Aalborg PBL model, control written reports detail the system and the system model, as well as the design of the controller and acceptance test. In this way, a team develops the whole project; students can compare the requirements set at the beginning of the project with results obtained at the end of the project; therefore, they can assess the effectiveness of the solution they have designed. Also, written reports allow them to observe how the quality of results and their effectiveness is enhanced when one team accomplishes the project, which is concentrating on obtaining the solution to a problem as the main challenge during a semester.

The Univalle PBL model stresses the rotation of student teams to solve a problem so as to make students able to work with preliminary information supplied by others and to satisfactorily execute an assignment to provide background so that others can continue the work. Also, it is a good example of applying PBL in a specific area of a curriculum that uses traditional education. The Univalle PBL approach was designed so that control courses match the traditional education used by other courses and students learn about several contexts and processes.

Although, during the development of the project, both the Aalborg PBL model and the Univalle PBL approach use knowledge from other areas like analogue and digital electronics, microcontrollers, programming, and electrical systems, the problem definition only involves courses or topics from control engineering courses.

4.5 Space and organization

The Univalle PBL approach uses traditional education spaces and resources to apply PBL in control learning. Aalborg University has specialized spaces and resources for PBL; for example, teams are provided with a group room and budget to develop the project tasks.

4.6 Assessment and evaluation

There is a marked difference in the written reports. While in Aalborg students deliver a thesis document with total results of the project and problem solution, in Universidad del Valle students deliver a short written report (similar to an article) at the end of each project stage, and this report has results that correspond to the objectives of the stage being executed.

In Aalborg University, the examination is oral and individual at the end of the semester; students are assessed by an external examiner. In the control area of the Engineering Program at Universidad del Valle, students are assessed by means of many evaluation activities that include oral presentations and written reports regarding project results.

The Univalle PBL approach involves peer-assessment and student self-assessment activities.

5. Concluding remarks

The technical objectives of the control engineering course leading to a Bachelor degree are very similar at the two universities. However, the PBL learning process is organized in very different ways. The analysis of the curriculum practice in one semester indicates that the Aalborg model compared to the Universidad del Valle model uses much more of a learner-centred approach, while the Universidad del Valle model is more teacher controlled. The universities are also different in the to student preconceptions about PBL, as the engineering curriculum at Aalborg University is based on PBL from the first semester and Danish students have—to some extent—used project-oriented learning in primary schools and high schools. The modeling and control theme is the first introduction to the PBL approach for students at Universidad del Valle and thus students do not have any previous experience of it.

Benchmarking of the reports shows that the differences are related to supervisor management, the problem analysis, interdisciplinarity, and the independence of the student work. Student outcomes are comparable regarding technical skills, and study of the reports shows that the learning in the project work regarding modeling and control methods is almost identical.

The Univalle model focuses on a teacher-structured method to offer students experience in the practical use of theoretical methods. The subject areas are divided into project stages to be reported separately, implying that the project tasks used in each stage are relatively short. The projects are very well-designed and delimited to offer students experience in the use of specific methods for modeling and control in the curriculum and to experience relevant practical use of the methods in the laboratory in problems related to local industry. The model stresses the rotation of student teams to solve a problem, to allow students to work with preliminary information supplied by others and to satisfactorily execute an assignment to provide background so others can continue the work.

The Aalborg model demands more student independence. There is one project covering the modeling and control objectives. The project proposals presented are less precisely formulated and it is up to the students to formulate their own projects within the theme of the semester. The projects can be in the laboratory or in direct collaboration with local industry. The work of students includes significant effort within project formulation, specification requirements, formulation of the control problem, identification of the relevant system dynamics to be modeled, qualified choice of the best suited control method(s), implementation challenges such as sensor and actuator problematic and real-time software development and assessment. Evaluation and testing of the methods in use is another important issue.

The comparison of the two PBL models clearly indicates that there are very large differences in the learning and practice from one model to the other. Even if the same technical content within modeling and control objectives is formulated, the analysis of the two systems indicates that the learning is very different due to the different focus in the PBL approach.

In the Univalle model the PBL element is based on the cognitive learning approach and emphasizes that all students gain experience in the use of specific modeling and control techniques in an industrial context. The learning objectives within the specified control techniques are ensured by several short teacher-formulated projects covering well-defined modeling and control problems. In this way it is ensured that all students gain experience of all methods in the curriculum.

The PBL element within control in the Aalborg model is a combination of the cognitive learning approach and the contents approach, focusing on projects covering all engineering aspects of industrial control tasks. Self-dependence and an interdisciplinary approach in combination with cohesive problem-solving methods are more important than experience within all theoretical methods. In addition to the experience with specific modeling and control methods, the Aalborg model emphasizes the importance of overview and well-founded choice of methods in the problem solving.

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