Teaching Logic Control Systems to Chemical Engineering Students
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Teaching Logic Control Systems to Chemical Engineering Students

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Abstract

Logic control systems was incorporated into the academic program of Chemical Engineering students at *Tecnológico de Monterrey*. Exploiting Active Learning techniques and own educational technology, a new experimental automatic control course was implemented. Experiences show that students get a deep learning as result of the activity performed. Also, several abilities and skills are learned and the gap between theory and practice is avoided through the experimental hands-on sessions.

Keywords: Logic Control Systems, Education, Active Learning, Batch Manufacturing

1. Motivation.

Four technical disciplines were selected as crucial to the progress of the chemical industry [1]: new chemical science and engineering technology, supply chain management, information systems, and manufacturing operations. Particularly, manufacturing operations require advances in six key areas where information and process control is one of them. Here, a high degree of automation and decision making is needed.

In the early 1980's, the market pressure for greater product variety forced a gradual shift from continuous manufacturing processes to batch manufacturing processes.. About 50 % of all industrial processes include batch processing. Batch processes have one or more process cells for several products or product variants. These processes demand several complex operations carried out in multiple-purpose equipments on plant designed for multiple products batch manufacture. Each chemical process is defined in terms of a list of ingredients, the recipe, and the instructions to transform this information into a batch of a given product.

Batch production puts high demands on the use of information technology. Important tasks in a batch plant include production planning and scheduling, recipe management and execution, resource allocation and arbitration, report generation, quality control, monitoring and supervision, and regulatory control.

A complete overview of the automation field is needed at universities in order to respond to these challenges. Automatic control courses for Chemical Engineering (*ChE*) students are only focused in continuous processing in many universities, where batch manufacturing have been ignored in these courses [2].

In today's globally competitive environment, effective collaboration is vital. One thing that is on the checklist for just about every hiring manager is experience working in teams. Skills such as critical thinking, problem-solving, communication, etc are also demanded by every hiring manager, even more than technical issues.

This motivates universities to develop better engineering programs that could educate students in skills and abilities that demand a competitive world. Active Learning (*AL*) techniques represent the best approach in preparing students with these characteristics.

Keeping these issues in mind an automatic control course that includes logic control systems based on *AL* techniques was designed and implemented.

The paper is organized as follows. Section 2 presents some principles that guide the instructional approach in our school of engineering. Section 3 briefly reviews important issues of *AL* techniques. Section 4 describes our educational technology. Section 5 presents our Educational Model. Section 6 discusses the developed teaching-learning system, and finally section 7 concludes the paper

2. Principles of the School of Engineering.

The academic programs of the school of engineering at *Tecnológico de Monterrey* must contribute to the 2015 Mission[1] and satisfy *SACS*[2] accreditation. Also, *ABET*[3] and *CACEI*[4] criteria must be satisfied.

Tecnológico de Monterrey is a multi-campus system that integrates 33 campi in México and several offices all over the world. Based on a wide consultation with industry leaders, students, faculty, and ex-alumni the new 2015 mission of the *Tecnológico de Monterrey is* to prepare students and transfer knowledge to ...

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[1] www.itesm.mx/2015

[2] www.sacscoc.org

[3] www.abet.org

[4] www.cacei.org

- promote the international competitiveness of business enterprises based on knowledge, innovation, technological development, and sustainable development.
- develop business management models to compete in a global economy.
- create, implement and transfer business incubator models and networks in order to contribute to the creation of enterprises.

…with this mission (among other objectives), *Tecnológico de Monterrey* and its community are committed to contributing to the educational, social, economic, and political improvement of México.

The Commission on Colleges of the Southern Association of Colleges and Schools (*SACS*) is the regional body for accreditation of higher education institutions in the U.S. Southern States and in Latin America that award associate, baccalaureate, master's or doctoral degrees. *SACS* evaluates an institution through 4 issues: principles of accreditation, core requirements, Comprehensive Standards (*CS*) and federal requirements. *CS* represent good practices in education and establish an initial level of accomplishment. Even *SACS* accreditation considers many more aspects of the institution; through this course some contributions to the following *CS* are given [3]: an appropriate use of the technology by the institution that enhances student learning for meeting the objectives of its programs. Also, the institution must provide facilities, services and learning/information resources that are appropriate to support its teaching, research, and service mission. The *Tecnológico de Monterrey* is accredited by SACS since 1950.

Accreditation Board of Engineering and Technology (*ABET*) is a well known recognized accreditor for college and university programs in applied science, computing, engineering, and technology. *ABET* is one of the most respected accreditation organizations in the U.S. The *Tecnológico de Monterrey* is accredited by *ABET* since 1993. *ABET* criteria effective for evaluations during the 2006-2007 accreditation cycle states that engineering programs must demonstrate that their students attain several outcomes (Criterion 3). Through this course, the (b) and (e) outcomes will be specifically promoted into the *ChE* academic program. Additionally, the (d) outcome will be reinforced:

(b) Ability to desing and conduct experiments, as well as to analyse and interpret data.
(d) Ability to function on multidisciplinary teams.
(e) Ability to identify, formulate, and solve engineering problems.

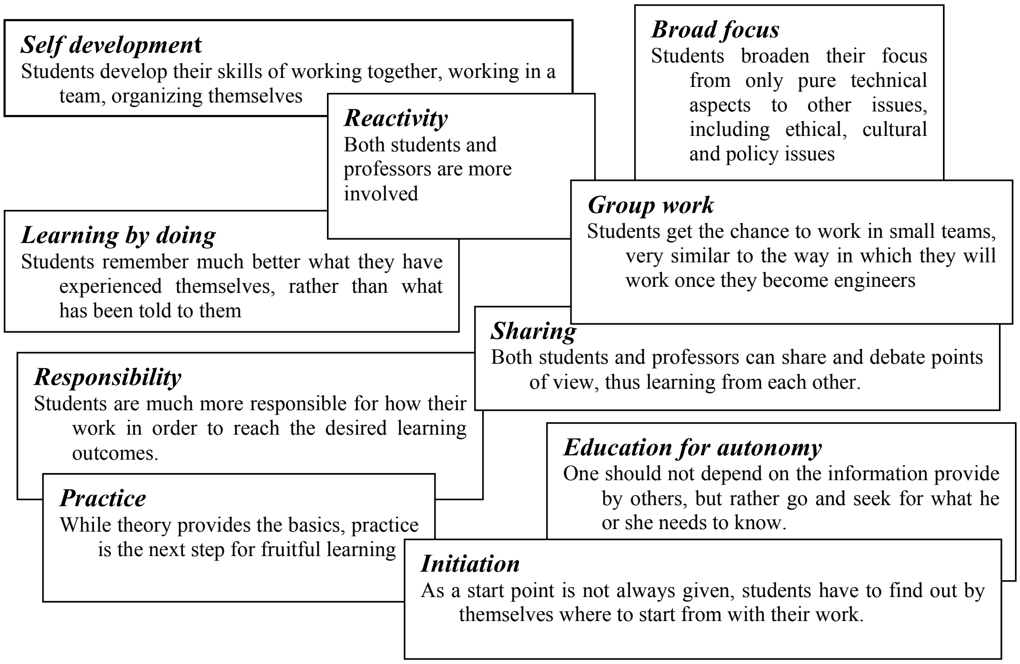
The Consejo de Acreditación de la Enseñanza de la Ingeniería (*CACEI*) is the Mexican accreditor that is commitment to enhancing the quality of engineering education since 1994. The *Tecnológico de Monterrey* is accredited by *CACEI.*

3. Active Learning techniques.

Active Learning (*AL*) techniques are based on the fundamental idea that a natural and deep learning happens as a result of the activity performed [4]. Exploiting *AL* techniques into conventional lectures and experimental sessions in this course, several skills/abilities are promoted. Also, better comprehension of the theory and practice is obtained by the students. *AL* techniques follow the way as in which people learn were important issues are [5]:

- People build knowledge starting from what they know.
- Abilities, attitudes and competences are more relevant than information and procedures
- Pedagogic competencies are needed for exploiting *AL* techniques

Using *AL* techniques, students are engaged in more activities than just listening, Figure 1 [6]. The design of this course was mainly based on two classical *AL* techniques: Problem-Based Learning (*PBL*) and Collaborative Learning (*CL*).



Self development
Students develop their skills of working together, working in a team, organizing themselves

Broad focus
Students broaden their focus from only pure technical aspects to other issues, including ethical, cultural and policy issues

Reactivity
Both students and professors are more involved

Group work
Students get the chance to work in small teams, very similar to the way in which they will work once they become engineers

Learning by doing
Students remember much better what they have experienced themselves, rather than what has been told to them

Sharing
Both students and professors can share and debate points of view, thus learning from each other.

Responsibility
Students are much more responsible for how their work in order to reach the desired learning outcomes.

Education for autonomy
One should not depend on the information provide by others, but rather go and seek for what he or she needs to know.

Practice
While theory provides the basics, practice is the next step for fruitful learning

Initiation
As a start point is not always given, students have to find out by themselves where to start from with their work.

Figure 1. Additional activities motivated by *AL* techniques.

4. Educational Technology

The *Logic Control Station (LCS)* was designed by *Tecnológico de Monterrey*'s professors keeping in mind several principles: *industrial components*, *fast connections*, *didactic diagrams*, *safe for the students*, s*afe for the equipment*, and *low operation cost* [7].

The *LCS* allows students to design combinatorial and sequential control systems. Student can design, build on, program and validate control systems using the most common industrial technologies (e.g. pneumatic, electrical and electronic) Figure 2.

The *LCS* includes a set of industrial actuators and sensors grouped in a power section and three control sections: pneumatic, electrical and electronic (i.e. PLC). Table 1 shows a brief description of each section.

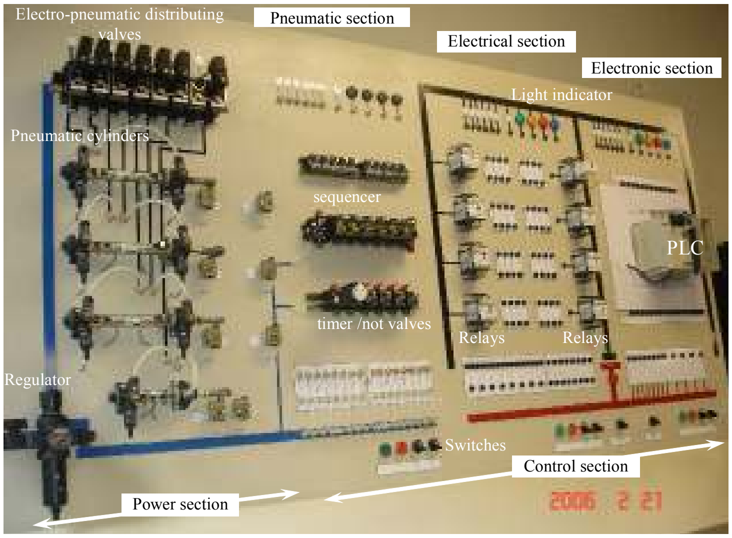


Figure 2. *Logic Control Station (LCS).*

Table 1 *Logic Control Station* description

Power section	*Pneumatic control section*	*Electric control section*	*Electronic control section (PLC)*
▪ It includes 4 pneumatic cylinders and electro-pneumatic distributing valves. ▪ It can receive electric or pneumatic binary command signals coming from any control section ▪ It includes sets of pneumatic, electric and electronic sensors that detect the position of cylinders and provide feedback to the control section	▪ It includes industrial pneumatic control valves (and, or, not, timers, sequencers) with fast connectors and provides interconnection to the power section. ▪ it is easy and fast to build combinatory and sequential pneumatic control systems.	▪ It includes a set of relays and timers with fast connectors. ▪ It allows the construction of electric ladder diagrams to control sequences in the power section. ▪ Implementing ladder diagram allows students to learn basic concepts that they will be able to extend to other approaches.	▪ It includes an industrial PLC with fast connections to actuators and sensors of the power section ▪ It also can communicate with a PC.

5. The Educational Model of the *Tecnológico de Monterrey*.

The Educational Model of the *Tecnológico de Monterrey* (*MET*[5]) has been characterized by its use of information technologies and the systematic incorporation

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[5] *MET* comes from *M*odelo *E*ducativo del *T*ecnológico de Monterrey.

of teaching techniques. *MET* includes a set of learning components through which the *Tecnológico de Monterrey* fulfills its educational goals, Figure 3 [8].

Students assume an active role in their learning process and build knowledge on the basis of their own experience and by reflecting on the same, under the direction and guidance of their professors. Students will acquire relevant, significant knowledge, learn to work collaboratively, improve their learning through continuous feedback from the professors, strengthen their ethical behavior, develop the capacity to conduct research and for self-directed learning, and be able to stay up-to-date and informed throughout their professional lives.

Professors rely on teaching techniques that enrich students' curricular education on the basis of a practical, professional approach achieved through teamwork and active participation. Some of the teaching techniques are: the case method, project-oriented learning, problem-based learning, collaborative learning, and other techniques centered on active learning, such as research-based learning and learning-service.

The *MET* incorporates the use of information and communication technologies, thus placing the course information and content at the students' disposal, and allowing students to broaden their learning options in settings outside the classroom, interact and collaborate with their professors and classmates, and have access to electronic data sources and other technological resources. The courses' learning activities are founded on constructivism and the development of the skills, attitudes, and values stated in the 2015 Mission.

Working with the *MET* demanded several important efforts. The training of professors in the use of teaching techniques, use of information technology and in the implementation of the *MET*. Improvement of the *Tecnológico de Monterrey*'s information technology in order to guarantee a top quality service. As a result, there has been a substantial increase in the use of information technological (i.e Blackboard[6]) from the basic level for simply transmitting information to students, to remote professor-student interaction or collaboration.

6. Teaching-Learning system.

Creating a course to achieve the principles described in section 2 based con the MET requires effort in three aspects: planning, instruction, and evaluation [9]. This paper is mainly focus in the instruction aspect, which implies the selection and implementation of the teaching techniques combining educational technology that allow students to reach learning objectives and skills and abilities [10].

The automatic control course is organized in 3 modules: 5 sessions for logic control systems, 3 sessions for continuous control systems, and 4 sessions for computer control systems. There are 4 additional sessions for introduction and formal exams.

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[6] www.blackboard.com

The logic control system module is designed to teach how to master tools to analyze and synthesize combinatorial and sequential logic systems and technologies used to implement industrial automation.

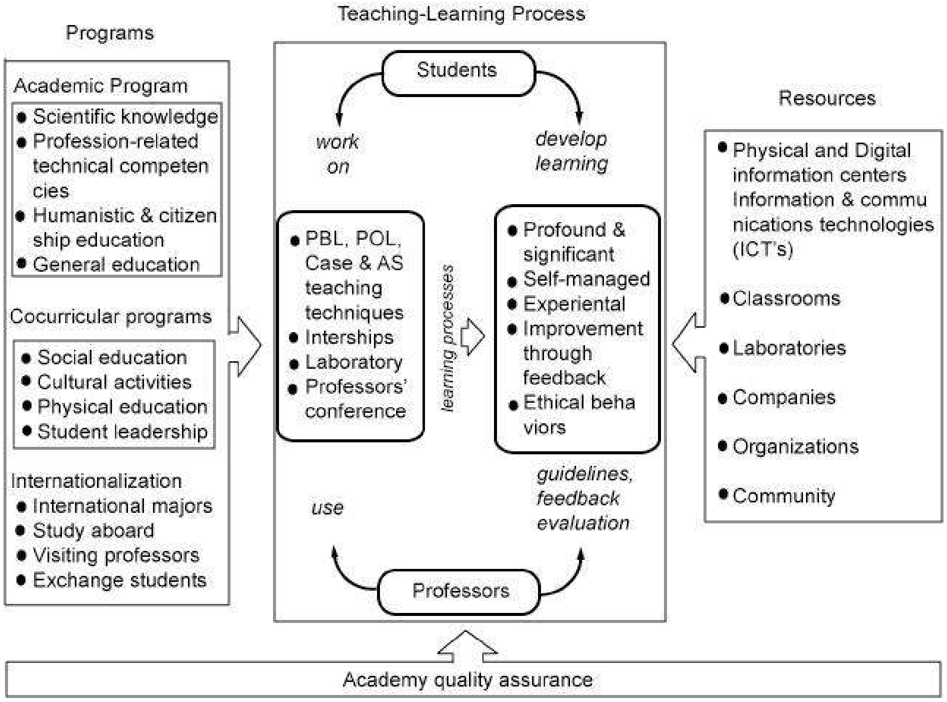

Figure 3. Educational Model of the *Tecnológico de Monterrey.*

A conceptual academic program is shown in Figure 4. A description is only included for logic control systems module that is focus in batch chemical manufacturing.

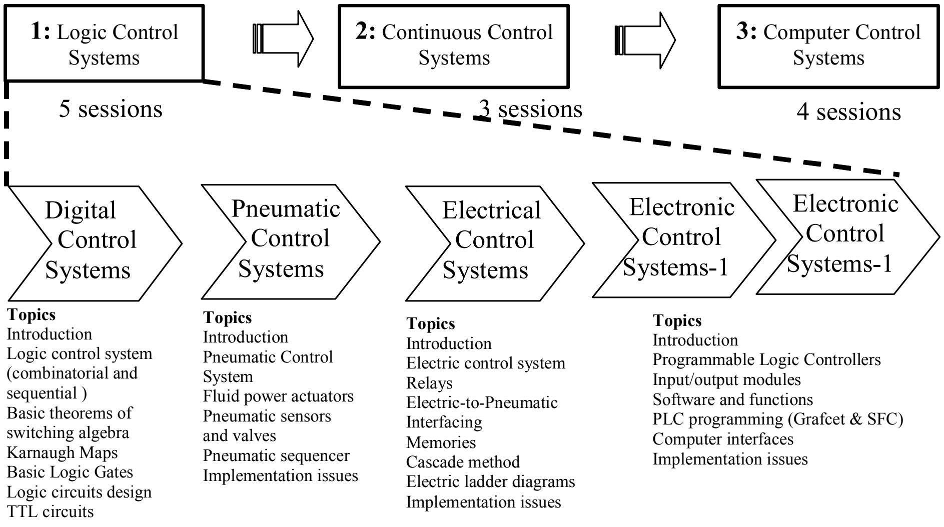

Figure 4 Academic program of the automatic control course

Every session considers 2-hr lectures, 3-hr laboratory sessions and 3-hr for additional activities (studying, reporting, etc), Figure 5.

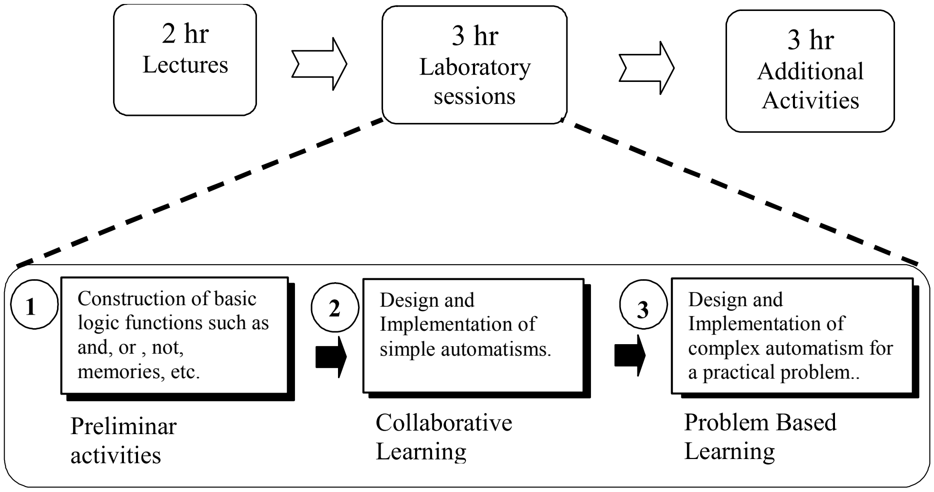

Figure 5. Teaching-Learning system.

Every session a full professor gives the 2-hr lecture for all students. The professor is responsible for generating the *AL* environment. Every lecture starts with a problem. Usually the professor gives the 50 % of the information and guides the student to complete their knowledge through assignments (homework, exercises, etc). The professor promotes autonomous learning activities exploiting the Blackboard system.

The 3-hr laboratory session has the same structure every week Figure 5. Students are organized in 4 teams of 3 students each one, every team will be working with a *LCS*. In the first part, the Teaching Assistant (*TA*) explains how to operate a specific section through simple examples, such as extracting/retracting cylinders, turning up/down indicators, etc. Students are asked to implement basic logic functions (and, or, not, memories). Every implementation demands interaction of all the members of the team. Usually, there are different possible solutions for assignments, so discussions appear naturally. Creativity is promoted if the students are asked for optimal solutions. Discussion of similar industrial applications is introduced.

In the second part of the 3-hr laboratory session, more complex logic control systems are designed and built linking the basic components and configurations. The problem specifications demand that students work in teams. *CL* is naturally developed. Sometimes, students support themselves for clarification and explanation. The *TA* makes sure the concepts are applied correctly by questioning the results.

In the last part of the 3-hr laboratory session, *PBL* is exploited. Students face a situation in the context of a chemical industry process. The general functional goals of a batch control system are specified. The solution of these problems requires an integration of the learned information. Analysis of several alternatives is needed in order to find the right solution. The *TA* plays two roles: consultant and client. The *TA* as a consultant supports students with the technical details of the equipment. Using the following example, the teaching-learning system will be discussed.

An evaporator concentrates a solution by vaporizing the water using steam as a heat source, Figure 6 [10]. The ideal conditions are concentrations between 30 and 45 % and an operating temperature over the 120 ^{o}C. An automatic start up operation is needed. The tank is filled by feeding a solution for 25 minutes; then a preheating step is carried out by circulating steam for 10 minutes. After the pre-heating step the continuous operation begins and the input and output valves are kept open. At the end, the output valve must be open for 30 minutes because the tank must be drained by gravity. The problem definition is ambiguous; this motivates student clarify goals.

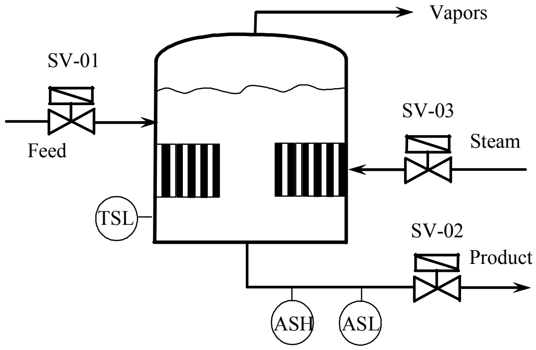

Figure 6 Evaporator system.

Students must define sensors and actuators for the batch control system. Then an abstraction of the problem is needed in order to represent every sensor and actuator as a particular element of the *LCS*. This step is no trivial; it generates a better understanding of the problem. Table 2 shows a summary of the process and system variables. Figure 7 shows how this problem can be implemented into the *LCS*.

Robust batch control systems demand the consideration of the all possible states, including faults. There are many interesting ways to implement faulty conditions for a complete test of the system. A faulty condition of a concentration sensor, for example, can be simulated with an "or" function between the sensor switch and a push button.

Several skills are promoted into the laboratory session. During the evaluation step, students must show the batch control system working properly for every condition. Students can observe the control system working by seeing the lights turning on/off, seeing and hearing the pneumatic cylinders moving right/left, etc. Even there is a big difference between controlling an evaporator and its simulated implementation; students are more involved with the behavior of the process because they can modify it by changing the switches that represent the sensors.

The evaluation step demands: higher-level skills such as analysis, synthesis, critical thinking, problem-solving, also high interaction between the each member of the teamwork. This interaction includes communication, coordination, etc because of physical constrains of the logic control station.

Table 2. Equivalences of process and elements of the *LCS*.

Variable	**Description**	**Physical representation**	**PLC I/O**	**State**
HC	High concentration switch ASH	Selector button	I1	Left : Concentration $\leq$ 45 %
				Right: Concentration > 45 %
LC	Low concentration switch ASL	Selector button	I2	Left :Concentration $\geq$ 30 %
				Right: Concentration < 30 %
LT	Low temperature switch TSL	Selector button	I3	Left :Temperature $\geq$ 120^{o}C
				Right: Temperature < 120^{o}C
S	Operation selector	Selector button	I4	Left: Stop (operation)
				Right: Start up (operation)
Iv	Input valve, FSCV-01	Double effect cylinder: -solenoid valve to extend	O1	Extend: Close
		-solenoid valve to retract	O2	Retract: Open
Ov	Output valve, FSCV-02	Double effect cylinder: -solenoid valve to extend	O3	Extend: Close
		-solenoid valve to retract	O4	Retract: Open
Sv	Steam valve, FSCV-03	Red light	O5	Off: Close
				On: Open

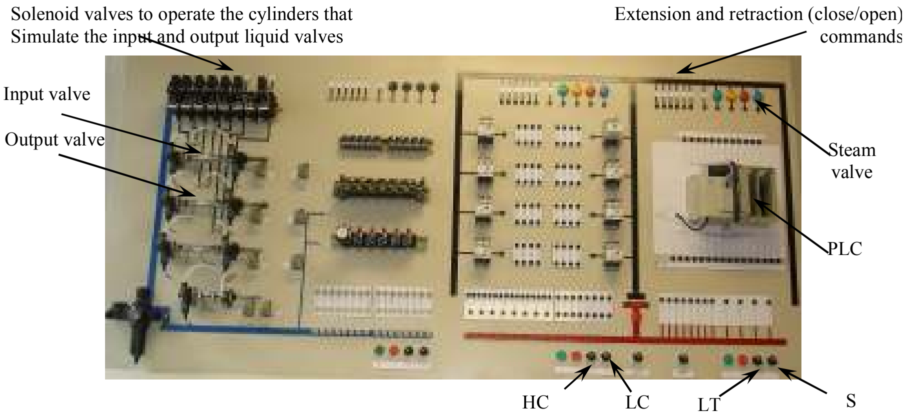

Figure 7. Process and control system representation in the *LCS*.

Every working team has its own personality. Figure 8 shows the level of interaction that typically working teams exhibit during the laboratory sessions [11]. Every square in this figure exhibits two relative dimensions: intensity of interaction versus elapsed time. At the beginning, (*stage I*) students need to check in with each other. After socialization, (*stage II*) students start reading the problem definition and trying to figure things out such as equipment recognition. Then, (*stage III*) students start talking about doubts, suggestions, proposals, argumentation, etc in order to find a solution. Based on their own conclusions, (*stage IV*) the solution is implemented where testing and evaluation are critical activities. After completion, (*stage V*) students interact less only for checking data, results, etc. Finally, (*stage VI*) socialization starts again.

A special attention of this level of interaction must be considered for several reasons. The laboratory session must be completed in 2 hrs. Socialization stages (*I* and *VI*) must be controlled (no killed). The stage *IV* is the main reason of the laboratory session, participation must be promoted actively. The stage *III* is important because the solution and implementation must be generated here.

The development of any skill is best facilitated by giving students practice and not by simply talking about what to do. The activities in each experimental session encourage two important issues: *thinking about* and *hands on*.

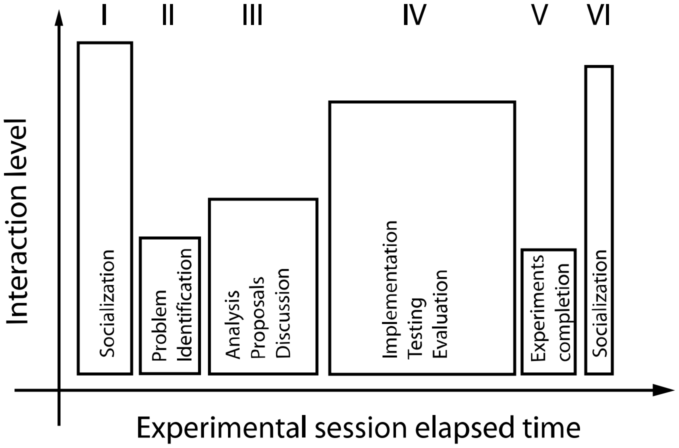

Figure 8. Interaction level versus experimental session elapsed time

The performance of a team is not only a function of the intellectual ability of its members, but also the extent to which the members have learned how to work effectively as a part of a team. Collaboration among people, processes and technology is essential to the future of manufacturing. It's a *win to win* that is delivering results, but something that has to be worked on, something that has to be learned. Many trends can be addressed with collaborative manufacturing strategies. Such strategies include creating a highly collaborative corporate culture, students must appreciate and work on.

A systematic process for looking at student achievement is needed. This assessment process must have several characteristics such as: it must be continuous, it must identification and document strengths, weaknesses, needs and improvements, it must report progress, definition of a plan for improvement and goals; analysis of its results with all constituents, and finally, it must review and change objectives and outcomes if needed.

As assessment method, scoring rubrics on learning outcomes were chosen. A rubric is a scoring guide that contains well-defined and systematically applied criteria. Rubrics are useful when a behavior or subjective issue have to be evaluated such as problem solving as a process, design as a process, skills with equipment, team work skills, and leadership abilities. In this course, there are 2-3 design problems in every experimental session where students working in teams must work with. Detailed rubrics are ideal as an assessment method.

Figure 9 shows a Learning Outcome Assessment Rubric for Learning Outcome (b)[7] *Ability to design and conduct experiments, as well as to analyze and interpret data.* With this detailed rubric, each student is assessed in several issues: (1) Problem, process and variables definition, (2) Response variable measurement and operation ranges interpretation, (3) Design of experiments, (4) Experiment planning and data collection, (5) Equipment operation, (6) Safety procedures, and (7) Statistical tools and analysis for improvement.

Each of the previous issues has a specific weight (w). Also, there is a suggested scale (s) for each score. Using this matrix, a better feedback can be obtained. However, sometimes it is recommended to derive a holistic rubric from the detailed rubric. A holistic rubric allows you to asses different skills of the students for accreditation purposes once or twice rather than on each experimental session. For example, sometimes writing skills are more important than designing an experiment or student competencies with laboratory equipment. Certainly, to asses all of the laboratory skills in each experimental session will be overload for everyone.

7. Conclusions

The need of education in batch chemical manufacturing is very important for *ChE* students because in most of industrial chemical processes there exists a portion of them that includes binary actuators and sensors and requires batch automation of recipes and sequences.

A module of logic control systems was introduced in an automatic control course that allows students to actively learn this technology and its applications to chemical processing. Students learn this material very well and enjoy making things happen with digital, pneumatic, electrical and electronic systems.

The gap between theory and practice is avoided through hands-on laboratory sessions. Even when *the logic control station* is not a chemical batch process, features that mechanical/electrical systems have are exploited: cylinders moving, lights on/off, closing/opening switches. The use of the presented *logic control station* has some difficulties for teaching batch control to *ChE* students: students must make an additional effort to demonstrate their solution to a logic problem establishing a non-unique relation between the elements of the problem and the elements of the experimental station. Also, this demands also more time and effort for the instructor

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[7] Thanks to Miguel A. Romero-Ogawa for providing tailored rubrics.

to evaluate and feedback the proposed solutions. The control systems are limited by the number and type of elements that are available, which may also drive the students to solutions that would not be practical in real situation (i.e. using push buttons as level sensors.)

Starting from a real problem, students can find the context for significant learning and what they need to find and learn. Working with real problems allows the students to develop concrete abilities. Students, assuming control over their learning process, may evaluate the results; so, theory may be better understood, thus facilitating transference to other contexts.

It was found it feasible to give *ChE* students the batch control systems module without spending too much time through hands-on laboratory sessions. *ChE* students do not only learn the control batch systems theory, but also they develop abilities, skills and attitudes (learning to learn, working in teams).

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Tecnológico de Monterrey, Campus Monterrey
Chemical Engineering Programs
Learning Outcomes Assessment Rubric
Learning Outcome (b): Ability to design and conduct experiments, as well as to analyze and interpret data

Item ↓ (Weight)	Unacceptable (s = 0)	Marginal (s = 1)	Acceptable (s = 2)	Very Good (s = 3)	Points Scored †
Problem, Process and variables (w = 1)	Does not understand the process, operation and response variables. Does not develop a problem statement	Understands the process, operation and response variables. Can develop a problem statement, but critical information is left out	Understands the process, operation and response variables. Can develop a problem statement with some information missing	Very good knowledge of the process, operation and response variables. Uses that knowledge to define a problem clearly	
Response variable measurement and operation ranges (w = 1)	Has severe difficulty setting levels for operation variables, as well as measurement methods for response variables	Has some difficulty in selecting operation levels and measurement methods for the response variables	Can choose operation levels to use. Knows about response variables and measurement methods	Can rank response and operation variables according to their importance. Can choose levels to use, measurement methods and their accuracy	
Design of Experiments (w = 1)	Needs assistance to choose the model to use	Can choose the model, but needs reassurance from the instructor	Can choose model correctly and confidently	Chooses models correctly and knows how to improve the model through sequential experiments	
Experiment Planning and Data Collection (w = 2)	Does not distinguish between repetition and replication. Needs assistance to plan experiments and collect data	Knows the difference between repetition and replication. Needs some assistance to plan experiments and collect data	Determines the need for repetition or replication. Collects data in an organized manner	Determines the need for repetition or replication. Plans and organizes experiments, carefully documenting data collected	
Equipment Operation (w = 2)	Can not operate instrumentation and equipment correctly and requires frequent supervision and help	Operates instrumentation and equipment correctly but fails to follow experimental procedure	Operates instrumentation and equipment correctly. Follows experimental procedure with few mistakes	Operates instrumentation and equipment correctly, following the experimental procedure carefully	
Safety Procedures (w = 1)	Practices unsafe, risky behaviors in laboratory	Unsafe laboratory procedures observed occasionally. Not always uses safety equipment	Very few laboratory procedures observed. Uses safety equipment most of the time	Observes laboratory safety procedures and uses safety equipment correctly	
Statistical Tools and Analysis for Improvement (w = 2)	Makes very little or no attempt to interpret data	Makes errors and omissions in the use of statistical tools for analysis, misinterpreting physical meaning of results	Makes few errors and omissions in the use of statistical tools for analysis. Interprets the physical meaning of results	Excellent statistical analysis and physical interpretation of results to make improvements in product or process	
†Points Scored = w×s				**TOTAL POINTS**	

Course Number and Title: ____
Name of Student/Team: ________________________________ **ID Number:** _________
Program: ______ **Reviewer:** ________________________ **Date :** ___________________

Figure 9. Learning Outcome Assessment Rubric.

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