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Educational Strategy Based on Active Learning For Mechatronics Labs

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Abstract: This paper presents an educational strategy for Mechatronics laboratories education which integrates the Tecnológico de Monterrey Educational Model, industrial technologies and equipment, hands-on activities, laboratory equipment based on Design for Mechatronics Learning (*DFML*) and an e-Learning platform to improve communication between teachers and students. An Automation of Manufacturing System Laboratory course is described where an industrial Flexible Manufacturing Cells (*FMC*) is used by the students. This industrial *FMC* was designed based on academic goals for mechatronics engineering students. Students have an intensive active participation in the experimental sessions. Students can integrate new sensors and actuators with industrial equipments such as Robot, *CNC*, *ASRS*, and so on. This feature allows students many independents layout combinations that are typical in industrial environments. The proposed educational strategy, based on industrial equipment designed to mechatronics practice, let to students how to deal with situations that may arise by multidisciplinary working teams to face conflictive problems in industrial environments. A final poll was applied to the student to assess the performance of use industrial equipment with design for mechatronics learning principles join with didactic learning techniques in an engineering course. The poll results let to come to a conclusion of this proposal improve the learning of engineering practice.

1. INTRODUCTION

Active Learning (*AL*) is the key point which Tecnológico de Monterrey based its educational model. The department of Mechatronics and Automation has been efforts to support its academic programs based on *AL* concepts and experimental laboratories session (centered in student hand-on activities).

In order to implement the Tecnológico de Monterrey educational model to exploit its maximum benefits. Tecnológico de Monterrey´s professors participate in the design of experimental equipment in automation fields (Morales-Menendez, 2005). The main target is to generate educational technology with industrial components to let students take part of their own learning. The present work highlighted the educational strategy model used on Automation of Manufacturing Systems Laboratory. Special features were added to integrate industrial equipment in order to Design and Flexible Manufacturing Cells (*DFMC*). A "Design for Mechatronics Learning" principle was applied.

The literature report many efforts to implement academic programs on engineering laboratories with commercial equipment but a few works built its own design; based on mechatronics issues of the academic program matches with AL issues. Several studies demonstrate how effective *AL* can be, if it is used properly. (Bonwell et al., 1991) conclude that this method improves students reasoning and writing skills, in addition to develop certain important attitudes. Evidence shows that discussions exceed traditional methods expectations in respect to retention of information, motivation and development of reasoning skills.

(Hill et al., 2001) show the benefits of using laboratory equipment specifically designed for *AL*. Performed tests show the ability to demand students to apply practical knowledge of the equipment used. In those tests students were able to come up with a solution to the given problem in a "learning" step, instead of being under pressure as if were a real problem.

A program called the Integrated Teaching and Learning program (*ITL*) was developed by (Carlson et al., 1999). This program is a clear example of learn-by-doing. This program consists in a laboratory where the hands-on technique is used. It was created keeping in mind the idea of having a multidisciplinary working and learning environment able to promote team work creativity, and problem solving abilities.

(Dori et al., 2003) present another program focused on science courses called the Technology-Enabled Active Learning (*TEAL*) project. The program is intended to change the way students receive information, as in traditional methods they are required to memorize facts without questioning the relationship with other scientific or nonscientific knowledge. The *TEAL* project is centered on an

AL approach, using an designed classroom aimed to provide a collaborative, hands-on and media-rich environment.

Different class formats had been applied by (Michael et al., 2001). One of them, where students solve problems in workshops, he applied collaborative learning not only to small groups but to the entire class; students learn from other students. The workshop format itself forces students to integrate information and knowledge to come up with a solution.

Since the introduction of computers in classrooms much has been done in order to take advantage of their potential. Communication systems have gain lots of attention because of their usefulness in transmitting information between teachers and students. A technology called Classroom Communication System (*CCS*) tries to support the interaction between people involved in the learning process.

(Boyle et al., 2003) analyze the implementation of *CCS* in large groups. The stand out that one of the main contributions of this technology is the quality and speed of feedback. Regardless of the size of the group teachers and students get almost instant feedback. This would be very difficult to achieve using traditional methods.

Another shown advantage is that students can quickly view how their personal answers match to the entire class. This enables them to keep track of their own progress relative to the other students. This advantage also let teachers identify which students are experiencing difficulties, information that they can use to adapt the way those students receive new information.

(Cook et al., 2004) present a guide to developing educational websites by integrating principles of *AL* with the unique features of the Web. Web-based learning is inherently learner centered and offers the flexibility of being accommodated to different schedules, distance learning and encouragement of self-directed learning. They emphasize the idea that designing a web-based learning course involves more than creating a colourful webpage. Instead, effective web-based learning requires a careful program design that integrates the best features of *AL* techniques and the Web.

(Morales et al., 2005) proposed the design and implementation of control topics laboratories for mechatronics courses based on academic programs. The present work is the extension of that reported effort.

Table 1 summarizes the state of the art of *AL* articles focused on educational engineering. Most of them applied *AL* methodologies to engineering classes and laboratories; others to the addition of internet technologies in order to improve communication between teachers and students. There are other few examples of laboratories designed to integrate hands-on and collaborative learning with real world problems. However, these laboratories use primarily PC based simulations for problem solving activities. As is showed in the summary, the present work is related to the application of *AL* techniques in a designed laboratory in order to be use for didactic purposes in Mechatronics courses. The laboratory has industrial equipment adapted to be used by mechatronics students in hand-on activities.

Table 1. References summary

Author	AL	PBL	CL	HO	Others	Lab	Eng.	CS	LC	Internet	IE	DM
[Bonwell91]	X											
[Carlson99]				X				X				
[Michael01]	X				X							
[Davis98]							X					
[Hall02]							X		X			
[Catalano97]							X	X				
[Lamancusa95]		X	X	X		X	X	X			X	
[Felder02]					X		X					
[Kirschner06]	X				X							
[Goodwin91]							X	X	X			
[Shallcross07]				X		X	X		X			
[Beaudoin95]		X	X	X		X	X					
[Boyle03]									X	X		
[Hill02]				X		X	X					
[Schank94]	X									X		
[Wang05]	X									X		
[Felder03]	X											
[Walker03]	X				X							
[Cook04]										X		
[Moreno00]										X		
[Prince04]	X				X							
[Dori03]	X				X					X		
[Barrado01]			X					X				
[Clough96]							X	X	X			
[Morales-Menendez05]	X	X	X	X		X	X	X		X	X	X
[THIS-WORK07]	X	X	X	X		X	X	X		X	X	X

(*AL*: Active Learning, *PBL*: Problem Based Learning, *CL*: Collaborative Learning, *HO*: Hands-On, *Other*: Other Techniques, *Lab*: Laboratory, *Eng*: Engineering Education, *CS*: Case Study, *LC*: Lecture Class, *Internet*: e-Learning Platform, *IE*: Industrial Equipment, *DM*: Designed for Mechatronics Education).

2. LEARNING STRATEGY

A novel learning strategy for Mechatronics Laboratories was applied in Automation of Manufacturing Systems laboratory course. The educational strategy implemented on laboratory sessions is divided in four major components (see Figure 1) one of which represents the educational model of the Tecnológico de Monterrey (Mijares, 2007). The other three components are targeted to complement and enrich the learning experience by letting students merge practical and theoretical knowledge. A web communication platform enables teachers and students to actively participate and collaborate with each other while not in the classroom.

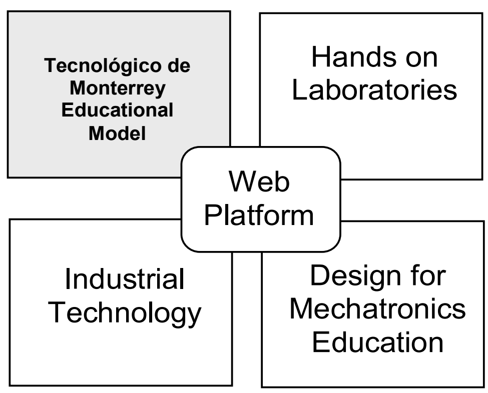

Fig. 1. Mechatronics Labs Learning Strategy

2.1 Tecnológico de Monterrey's Educational Model

The Tecnológico de Monterrey's educational model is student and learning centered, instead of the traditional model which is teacher and teaching centered. Its model is based on two main principles: constructivism and experimental learning. Constructivism is based on the premise that knowledge cannot be transferred from person to person, but it is constructed by the own individual. On the other hand, experimental learning is based on the principle that we all learn from our own experiences.

The educational model applies *AL* techniques such as collaborative learning and self learning, develops abilities, attitudes and values in a planned and programmed way. In addition to educational techniques, the educational model uses technological resources to enrich and make more efficient the learning process. *AL* techniques are widely used in laboratory classes as they enable students to learn by doing. They are actively working with laboratory equipment and interacting with their classmates. The main idea is that students develop, besides knowledge, abilities such as self learning, critical thinking, creativity, team work, use of information technology, effective communication skills, leadership and work and quality culture.

Collaborative learning is applied through the semester by making small work groups (4-6 students). This makes it feasible and easy to assign each student a different role in order to perform according with industrial activities. Roles are switched according to session topics and previously assumed roles. Eventually, all students would have assumed all roles. In the final project a *PBL* technique is used.

2.2 Industrial Technology

Laboratories are equipped with industrial equipment and modern technologies. Students get the added value of working with equipment that is actually used in industry. Different sessions are used to deeply study each of these different equipments and technologies. Real industrial world activities are done, from setup to operation and fault detection, diagnosis and correction. Also students program the equipment to perform different functions. Students are encouraged to solve eventual (and unexpected) problems that may arise in order to get them to think critically and come up with a solution.

2.3 Design for Mechatronics Education

Industrial equipment brings along a series of inconvenient issues when dealing with academic functions. These issues are related to the use of rough and dangerous materials, expensive maintenance and operation related accessories and materials and, because of its academic use, often miss-use of the equipment.

Because of these issues, the manufacturing equipment was specifically integrated taking into account academic-orientation. The design goes beyond the hardware and software setup. A major characteristic of the equipment is the possibility of redistribution or rearrangement in order to isolate technologies in groups to get a better planning of the laboratory sessions. These are independent of each others for any sessions and can also work together in a session as an integrated manufacturing unit.

Laboratory sessions can be planned by the professor using a unique technology, grouping two or more technologies or using the total technologies available. This issue encourages the flexibility to apply the collaborative and *PBL* due to be easier to assign learning tasks to student teams about specific technologies. This design lets an optimal organization of formed collaborative teams by a small number of students because the students can focus on the assigned technologies independent of other technologies present in the laboratory. It is possible to group different teams to use different kind of equipment in the same session and then make a final session where each team can show its experiences with the technology used. This equipment let to apply *PBL* using complex problems due to the students can be group in different sub-groups to deal with different technologies to face a big problem.

2.4 Hands-on Learning

The learn-by-doing technique is well suited for laboratory work. It helps students to acquire knowledge and skills through work and experience. This technique actively engage students in a total learning experience where they learn to think critically and process information by using hands-on materials and operating machines. Understanding and new knowledge is acquired by doing in-depth analysis of the materials, equipment and phenomena. Sessions are designed to let students take control of the equipment to perform activities such as operation, fault detection, diagnosis, corrections, programming and implement real world projects.

2.5 Web Platform

The laboratory is supported by a web e-Learning platform, the BlackBoard Learning System. This platform is an academic suite that integrates advanced tools to improve the learning process. Virtual communities can be created using its communication tools, which enable teachers and students to actively participate in discussions and email conversations. All laboratory educational information and resources are shared and ready to be accessed anytime, anywhere. Interactive features include a file exchange section where students upload their reports and the teacher, as soon as the reports are assessed, uploads them in that same section. The platform also provides administrator tools for teachers, which enable them to post announcements, send emails, organize students in groups and even store student grades online.

3. AUTOMATION OF MANUFACTURING SYSTEMS LABORATORY

The Automation of Manufacturing Systems laboratory has two identical Didactic Flexible Manufacturing Cells (*DFMC*), one of which is shown in Figure 2. The equipment was integrated and implemented by Tecnológico de Monterrey's Manufacturing Research Center. Special features were considered on the design of the equipment in order to follow the educational model.

Laboratory equipment is similar to the one found in industrial production workshops. Each cell consists of the following:

- Assembly Station with Motoman UP-6 industrial robot conditioned with an automatic tool change module driven by an Allen Bradley Micrologix 5500 *PLC*.

- EMCO PCMill 155 CNC Milling Center with Fanuc Series 21M controller and 10 cutting tools magazine.

- Material Transport Systems with an inspection vision system equipped with 542C DVT camera and also driven by Allen Bradley *PLC* to coordinate the system.

- Automatic Storage and Retrieval System (*AS/RS*) with capacity for 12 compartments. The system has a robot type rotrix to storage/retrieval operations. The system has Devicenet fieldbus in order to use sensors and actuators. The systems is driven by an Allen Bradley Micrologix 5500 *PLC*.

- A control station with 2 PC coordinates the main operations of the cell. One of them coordinates control actions and the other run applications process.

Equipment is connected using fieldbuses such as: DeviceNet, ControlNet and Ethernet. Software is used to support processes and production management like *PP&C*, *CAD/CAM* and *CNC* simulation.

Fig. 2. Didactic Flexible Manufacturing Cell

The cells are designed with special features so students can participate actively in the laboratory sessions. The cells have connections points where students can connect new sensors and actuators depending on their own strategy to face the implementation in laboratory sessions or final project sessions.

The equipment provides the flexibility for the professor to plan laboratory sessions focus on different technologies. Many distributions of the equipment are available in order to cover topics related with all the syllabus of the course. Figure 3A-C shows more common combinations in the laboratory: industrial robot with *CNC*, industrial robot with transport system, transport system with *AS/RS*. Figure 3D shows the rails that let assembly station and the industrial robot be isolate to work as a one manufacturing unit independent of the manufacturing cell. The control software can be used by the students to modify current equipment functionality or/add new functionality according to the problem they are solving.

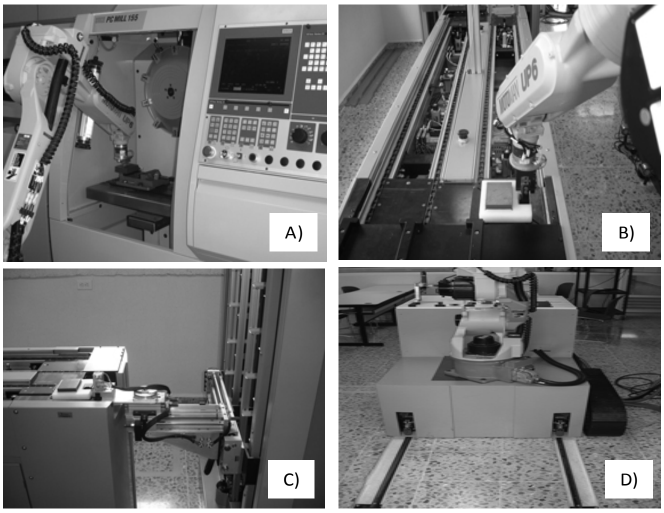

Fig. 3. Equipment Didactic Issues

4. STUDY CASE

This educational strategy is applied during the Automation of Manufacturing Systems course through one semester. Each cell of the laboratory is used by small groups of students per session, allowing all students to completely involve in the different learning activities.

There are 16 laboratory sessions (see table 2) divided in themes where each section is focused in working with a specific technology and equipment. Thematic contents start with an overview of the technologies involved in the automation field. Then, several sessions form the technologies theme, where each technology is tested separately. At the end of the laboratory sessions, an integration theme is done, where students learn how machines communicate each other in order to perform collaborative functions. Final sessions, constitute the final project; this is the application theme, where all knowledge is applied in solving a real problem. Laboratory sessions are as well divided according to the learning technique used: Collaborative Learning and *PBL*. Professors and instructors are trained in those *AL* techniques according to Tecnológico de Monterrey's educational model.

Table 2. laboratory Sessions Schedule

Theme	Session	Activity
Introduction	1	Introduction to the DFMS
Technologies	2	CNC – Introduction & Setup
	3	CNC – Basic Programming
	4	CNC – Advanced programming
	5	Robot – Introduction & Setup
	6	Robot – Programming
	7	AS/RS & Conveyor
	8	Vision Inspection Systems
Integration	9	Industrial Fieldbuses & Integration
	10	Central Control
Application	11-16	Final Project (PBL)

4.1 Laboratory Sessions - Collaborative Learning

Laboratory sessions are totally student centerd. At most groups of six students are created to perform laboratory activities. When working in small groups each student contributes with ideas, making the other students enrich their own ideas. Discussions may arise, which makes everyone think critically, defend their own proposals and eventually accept other student opinions. They also develop tolerance and fortify self-esteem and self-confidence. Students take different roles like security engineer, planning and development engineer and continuous improvement engineer. By assuming one of these roles, students are encouraged to think as if they were actually working in industry.

Session 1 is an introductory session; it prepares the students for the next sessions by letting them know what all the elements they will be interacting with are. They are given general information about the operation of each component as an isolated unit or integrated as a *DFMC*. In sessions 2-4 the Computer Numerical Control technology is studied using a Milling Center. Robot sessions are similarly organized to *CNC* sessions. Automatic Storage/Retrieval Systems (*AS/RS*) and Conveyor Systems are studied in session 7. Students learn how to operate both systems and how to integrate them in order to perform actions together such as sending material to the Conveyor and storing it in the *AS/RS*. Vision Inspection Systems are taught using a general purpose industrial camera. Session 9 is considered for working with different industrial fieldbus from the plant level to the management level. Related activities are configuration of different devices and protocols and establishing communication among the different components of the *DFMC*. Session 10 integrates the aforementioned sessions, as students learn how the process planning and production control process take place. Using *HMI* software and planning software students integrate all components of the *DFMC* to carry out a complete product manufacturing process.

All sessions are structured as follows: first, the teacher gives an introduction about the technology, equipment and applications that are to be covered. In sessions where programming is involved, generally all students participate in creating the framework of the program, and then students add their own specific functionality. After the brief introduction, students review their corresponding roles prior heading to the assigned *DFMC*. Once in the *DFMC*, teams interact with the equipment as the instructor is given directions. At the end of the session students gather and comment their own experiences: problems, solutions, etc. Finally, a technical report should be written.

4.2 Final Project – Problem Based Learning

Sessions 11-16 correspond to the final project where students apply all the acquired knowledge. *PBL* is exploited; students are presented to a certain problem and they come up with the solution and not only the presented problem but other minor issues that may arise due to the use of the equipment and material handling.

The problem is not presented as is, but it is introduced by real industrial scenery where students have to think, discuss and come up with the problem that needs a solution. The scenery enforces a simulated industrial environment where the students must organize as a consulting firm to participate in a competition against the other consulting firm formed by others.

Besides, the laboratory activities students write technical reports. The goal of these reports is to encourage students to use their own words to describe what they have learned. Besides the reports, students are asked to write operations manual, which include all setup, calibration and operation procedures for every *CDFM* component. One *PBL* implementation example was a scenery of toy company when the student teams had to manufacture a Hummer-type car toy with most possible low cost price and the better high productivity in the manufacturing cells of the shop floor of the company (in this case the manufacturing cell of school laboratory). The student teams were involved in an environment of competition because just the best three projects got extra points to the course final grade.

First the student teams analyze the scenery and understand the problem. Generate ideas of possible solutions. Build a list of what the team knows to solve the problem and build another list of what the team need to know. The teams do a plan to investigate possible solutions and define the problem. Once the team determine how want to face the problem, the students design a strategy plan and take different roles. The teams do the detailed engineering of their hummer-type prototype. Sketches, Drawings, *CNC* programs, robot programs, *PLC* programs, inspection programs and production planning are realized. After, the teams do the manufacturing run of the prototype on the equipments and check their time and cost.

In the final session of laboratory, the teams show their results and do the manufacturing run of the prototypes with the cells. An evaluation committee assesses (integrate by professors and industrial advisors) each project according with the rubric of the *PBL*. The issues evaluated by the rubric are quality of the prototype, efficiency of the manufacturing run, economic issues, quality of the engineering design and final report. The teacher informs the *PBL* results and determines the general learning conclusions of the course. Figure 4 show a hummer-type car toy manufactured by students in the *PBL* final project.

Fig. 4. Example of Hummer-type car toy manufactured in the *PBL* final project.

5. RESULTS

At the end of the semester students have gained experience in working in teams, meaning that they have learned how to express their own opinions and tolerate and accept other students' behaviours and opinions. In addition to the collaborate abilities they have gained they have also learned how to work with the industrial equipment.

Planning activities are developed by taking in account multidisciplinary real world roles like in industrial environments. In each session, the team can designs its own project master plan and follow it through different stages until the solution has been reached. Students also develop writing skills to elaborate technical documentation such as engineering reports, white papers and manuals. In the final project students learn to solve a complex problem taken from a real industrial application. The students gain sensitivity about problems of manufacturing automation projects.

In the last session of the course, a survey was applied to students when the main issues were about the equipment design, the joined use of the collaborative and *PBL* learning techniques and the general opinion of the course. Figure 5 shows these results. The firs question was: the equipment design help to apply better the learning techniques in the course? The second question was: Are you agree or disagree with the use of collaborative learning and *PBL* at a same course of laboratory? The third question was: What is your general opinion of the course?

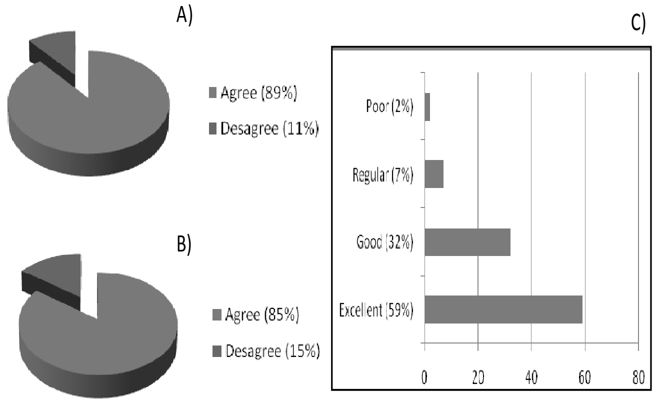

Fig. 5. Results about equipments design (A), use learning tech (B) and general opinion of the course.

6. CONCLUSIONS

The proposed educational strategy for Mechatronics laboratory reduces the learning curve associated with automation and manufacturing equipment operation and project planning because they worked with equipment that they will find when working after they graduate.

From the point of view of the collaborative working, students learned how to deal with situations that may arise in a multidisciplinary work team in their future works due to personal differences or not everyone working equally. Dealing with these issues prepares students to face related problems in industrial projects. This allows students to have a better management of the situation. The e-Learning platform is of great aid since collaboration between teachers and students takes place in real-time no matter where they are. The inclusion of communication tools helps prepare students for the globalized world where email and remote conversations are very common (virtual teams).

Since professors, trained in the educational model, are the responsible for the design and implementation of the manufacturing cells the laboratory equipment; so, this systems have the needed educational characteristics. The fact that the laboratory was designed focus on Mechatronics career needs makes it possible that learning can evolve at didactic stages in reasonable time in contrast to the pressure and reduced time present in real automation manufacturing projects.

Finally, the presented Mechatronics Laboratory Educational Strategy supported by Tecnológico de Monterrey's educational model, hand-on activities, industrial equipment and special design for Mechatronics education let the students acquire team work abilities and know-how technologies that companies expect from applicants when seeking for a job.

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