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Product Life-Cycle Management Tools and Collaborative Tools applied to an Automotive Case Study*

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Learning engineering nowadays requires acquiring the necessary skills to remain competitive in an increasingly flat world, as well as the ability to deal with practical problems using edge technology. Modern learning techniques attempt to compensate some of the shortcomings suffered by more traditional approaches, by including real-life industrial problems in the academic environment. The main contribution of this paper is to explore a Collaborative Learning Method to achieve the integration of learning techniques, Product Life-Cycle Management (PLM) and collaborative tools to tackle projects for the automotive industry. The method is implemented and validated via a case study on design engineering.

Keywords: Collaborative method; POL; manufacturing; PLM tools; collaborative tools

INTRODUCTION

NEW COLLABORATIVE LEARNING METHODS have become an important area of research to improve educational techniques in engineering. The traditional educational platforms that have been used during the last decades are not ready to support actual interactions between professors and students.

The traditional educational scheme, in which students receive theoretical information from the teacher, without actually applying such concepts, has a reduced impact on their effective learning. Modern advances in educational methodologies allow the improvement on some of these drawbacks, enhancing the value of future engineers working in this globalized and flat world [1]. Alternative learning approaches promote collaborative work among team members and with the advice of expert professors—geographically dispersed—who guide the learning process.

There is an alternative. We present a collaborative method that employs different learning techniques such as PBL or POL to solve an industrial problem with the participation of a team of professors, engineers and students who remotely collaborate with the assistance of information technologies. The application of this method is illustrated by solving a problem for the automotive industry using PLM tools for design engineering.

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LEARNING ENVIRONMENT AND TRADITIONAL TECHNIQUES

Learning techniques have been the subject of intense research [2, 3, 4, 5]. Several theories have been developed in an attempt to explain the different mechanisms for individuals to receive, assimilate, generalize and synthesize new knowledge. New channels for receiving/transmitting information (beyond the obvious audio-visual) have also been identified and weighed on the basis of efficiency and accuracy. This effort has led to a deeper understanding of the subject, bringing scientific weight and measurability to otherwise empirical matters.

In spite of this vast amount of research and improvements, traditional learning environments are still widely applied in classrooms around the world. This established approach is based on the instructor's role as a main source and transmitter of knowledge. The information is almost exclusively transmitted orally (in lecturing sessions), with the instructor performing a monologue-style speech reciting already digested concepts. This activity represents a large percentage of the learning process [3, 4]. Although the use of additional resources is unrestricted (i.e. textbooks, audio-visual, software, etc.), these can be heavily filtered by the instructor's views and opinions, thus losing accuracy and independence. Learners could still complement the perceived knowledge via alternative sources (i.e. books, technical notes and peer discussions), however, there is scarce motivation to do so and their reflexive skills remain largely unused [2, 4]. Thus, most would prefer having this complement via personal coaching.

Under this scenario, students' role remains passive (or reactive, at most), without much contribution to their learning process. This disparity in performed roles is often perceived by students as a lack of empathy from the instructor, thus adding a new bottleneck and setting conditions for frequent misunderstandings and unchallenged errors. The latter are a source of frustration for the instructor and sometimes disappointing evaluation's results.

Rigid evaluation formats are another strong feature of traditional learning environments. These are, with few exceptions, restricted to a questionnaire handed out by the instructor (oral, written or both), in which the student is asked to solve textbook-like problems related to previously covered material. This format fails to address a number of issues, also discouraging the development of essential skills in students. Some well-known disadvantages are: [3, 4, 5]

- inability to generalize new knowledge from previously known concepts;
- inability to recognize variations of previously known concepts, when taken out of the context in which they were learnt;
- inability to apply known methodologies to 'open-end' problems, i.e. when the specific question to be answered is unfocused. These problems arise frequently in engineering design;
- the available channels for receiving information are almost restricted to audio-visual, associated to short-term memory and poor insight;
- essential life-enduring skills such as creativeness, reflexiveness, abstractiveness, etc. remain undeveloped.

Traditional learning environment promotes techniques in which the knowledge absorption level ranges between 10 and 50 per cent for learning through reading (10 per cent), listening (26 per cent), seeing (30 per cent), seeing and listening (50 per cent) too low for any standard [6, 7]. Learning techniques based on Active Learning [8], Constructivism [9] and Reverse Engineering [10, 11] concepts, aim to further increase this efficiency.

A shared principle is to incorporate students into the learning process, actively generating and assimilating new knowledge. This does not dispute the importance of traditional classrooms with knowledgeable faculty and quality textbooks. The instructor's role remains quite relevant, ensuring that quality information flows in as many as possible channels, also encouraging self-learning, exploration and a 'hands-on' approach. Examples of these new trends are the Multiple Intelligences theory [2], stating that there are about 8 types of intelligences from which we usually recognize only two: Verbal-Linguistic and Logical-Mathematical. Another strong proposal is the Kolb's Learning Model [3, 4, 5], which argues that the learning process should be grounded on experience, thus linking intelligence with person-environment interaction.

Experimental learning theory provides a holistic model of the learning process and a multilinear model, both of which are consistent with what we know about how people learn, grow, and develop. The theory is called experiential learning to emphasize the central role that experience plays in the learning process [3]. Kolb considered four main steps of the learning process: Hypothesis, Experience, Reflection, and Abstraction. If properly followed, this flow would ensure the generation of new and correct knowledge [3, 4].

Active Learning (AL), Project Centered Learning (PCL) and Problem Based Learning (PBL) [11, 12, 13, 14] have already become established tools to promote active engagement of the students and instructor into the learning process. Collaborative Tools (i.e. Blackboard® platform) have emerged as the 'spinal chord' of learning activities, acting as supporting tools of the increasingly complex interactions between students, instructors and external players alike.

POL is one of several active learning methods devised during the last decade in the fields of behavioral and cognitive sciences [15]. With POL, students work on a single guiding project for an entire course. Students organize themselves into teams and play different roles, either sharing information or providing feedback within their teams. Since most of the learning process will take place outside the realm of the computer system, learning is simply assumed whenever there is evidence of its existence.

According to [15, 16] the POL technique provides the following advantages: on designing a project-orientated course the potential application of interdisciplinary knowledge is taken into consideration, thus the students can appreciate the relationship between different disciplines in the development of a particular project. In addition, course activities are focused on exploring a practical problem with an unknown solution, hence the search for open solutions provides to the students freedom to create new knowledge [15, 16].

Even though PBL advocates learning through experiences [17] it shares some characteristics with POL because in both techniques, case studies are 'authentic, curriculum-based and often interdisciplinary' [18]. However, POL integrates one long-term project which can be partitioned in several tasks, allowing students' organization into teams.

Cooperative learning (CL) involves the cooperative aspects of the students working in divided teams, however collaboration implies a common task with information systems to support communication. These aspects of CL and collaboration are used in the case study but not as main learning techniques.

An additional strategy is 'team teaching' which consists on a team gathering professors, instructors and experts in the subject or related disciplines. This team establishes and maintains a

Table 1. IT and PLM software tools used for collaborative work

IT/PLM tool	Functions
E-learning platforms	Management of course materials, sharing of information and feedback in a group.
E-mail	Direct feedback between members
Product data management (PDM)	Management and sharing of product information structured within electronic files.
Voice over Internet Protocol (VoIP)	Two-way real-time audio conferences using Internet.
Videoconference	Can be either web-based or with special equipment.
Instant messaging services	Real-time conversations between two or more members.

suitable learning atmosphere and promotes contributions among member. Course dynamics is benefited by the different teaching styles of each staff member [19] and their specific knowledge background.

On constructing a Collaborative Teaching Method, some of these learning techniques and theories were considered.

PLM TOOLS AND COLLABORATIVE TOOLS

Theoretical knowledge falls short of meeting the rigid competitive requirements of engineering students in a flat world. Modern engineering education requires tools to support student's experiential learning and a proper environment orientated to design engineering projects realization. This section reviews the concepts of Product Life cycle Management (PLM) tools and collaborative tools which could be applied to enrich a learning experience on the field of design engineering.

The life cycle of a product encompasses the holistic view of its entire development, in which several phases can be identified: product design, process development, production, distribution, use and disposal [20, 21]. For design and manufacturing industry, PLM is an approach to integrate information and knowledge produced along the product life cycle, thus promoting innovation [21, 22]. A PLM environment could function as a collaborative platform for multi-disciplinary teams involved in product or process development. PLM supports information sharing and work distribution via technological platforms and software. These software systems are named 'PLM tools' [20, 22] and they enable design and manufacturing engineering environments. PLM tools are commonly used for the realization of design engineering projects as they are integrated into commercial software for CAD/CAM/CAE (Computer Aided Design/Computer Aided Manufacturing/Computer Aided Engineering). Commercial brands widely known are: Dassault Systèmes®, PTC® and UGS®.

Product Data Management (PDM) software is one PLM tool that helps to organize the documents generated along the product life cycle [22, 23]. In a PLM environment the main role of PDM systems is to provide support to the many activities of the product lifecycle. Other PLM tools to support CAD/CAM/CAE are also required to carry out the design project. PDM software uses databases as repository for different types of documents [24] in their native format with the purpose of organizing, maintaining and making information and electronic files available to all design actors at any stage. Version control on files and user privileges for system access are typical on PDM software [22, 23]. For this reason, such PLM tools are powerful resources for enabling a collaborative engineering environment [22, 25].

Collaborative engineering concepts are commonly implemented on design projects executed asynchronously by a team of design engineers, who are connected through virtual spaces to share project information and knowledge [24, 26]. File exchanging (or publishing) using PLM systems would ensure the availability of updated files to course students. However, the dynamic nature of a particular project might need other characteristics beyond the ones offered by PDM systems. PDM software is used to publish information regarding product development but not to assist team direct communication or personal feedback [23, 24].

This paper argues that a set of collaborative tool technologies should be used to complement PLM tools. The integration of these Information Technologies (IT's) would lead to a successful interaction and information sharing between team members. As a consequence, communication regarding instructions, advice and comments on a design project development could easily flow between teachers and students involved.

Table 1 structures common IT's and PLM tools according to their functionality. Tools cited in Table 1 are very important to make possible the implementation of the teaching method proposed here.

A COLLABORATIVE METHOD FOR TEACHING

The hypothesis of this research is that modern learning methods orientated to solve real manufacturing industry problems require a suitable combination of:

- PLM tools;
- educational didactic techniques such as POL, PBL or others;
- collaborative platforms.

These new methods are required in engineering education to effectively blend a team of professors, project leaders from industry and students working together collaboratively at different geographical places. We call this blend a Collaborative Method for Teaching.

The use of PLM tools supports the product design process as exemplified in [27]. As reviewed in last section, PLM tools and IT tools used together as collaborative platforms could enrich a design project through the use of their related software such as: BlackBoard®, SmarTeam®, TeamCenter®, ENOVIA®, e-mails, web-based group portals, web-based video conferences, etc. (refer to Table 1). The proposed collaborative teaching method combines such digital tools and POL technique to tackle the communication barrier caused by the geographical distance between course students and facilitators. Geographical distance should not be an obstacle for education and interaction between teachers and students [28]. For this reason the Collaborative Method for teaching presented in this paper requires a particular logistic operation between team members (teachers, students and industrial partners) to use software tools mentioned earlier.

The collaborative method also considers the multidisciplinary nature of the projects in which students can apply their knowledge through the use of academic tools. With this working method, students should learn by themselves, test their skills and innovative ideas, relate to and understand enterprise needs, while experiencing the communication difficulties among different departments within a real enterprise.

The approach of this collaborative method consists of the following steps:

- An industry identifies the need to have a new project, involving product and/or process development. A teacher or teachers with a matching knowledge background are located.
- Communication between the industry project leader and the lead teacher of the university is established to agree a collaborative project. Such a university should already have a course to accommodate the project needs according to the required educational level of the students.
- The lead professor forms a team with other expert teachers, even if they are located in other regions or countries.
- The most convenient learning technique (POL, PBL, CL, etc.) to reach the proposed objectives is selected by the members of the teaching team.
- The communication tools and PLM software are identified and made ready to be implemented allowing the team members to work in different locations.
- Project tasks, milestones and outcomes are outlined by teachers and the industrial 'client'. Project metrics are also set by them but the team of teachers defines the course evaluation method within university parameters.

The project defined could be focused on a process improvement, a new technology application, product development or problem solving, among other options. The existence of academic courses related to the industry needs is an advantage that gives a chance to solve a variety of real problems. The lead professor searches for other teachers with expertise on the different areas which the project involves. The 'team teaching' strategy aims to guide and integrate the work of the students from different engineering areas and perspectives.

When all the structures proposed (team teaching, collaborative learning scheme and IT Platform) and links (industry need–academic course) are set in place the project can be executed by students and supervised by the facilitators. If the project is effectively carried out it and provides a valuable solution it should be proposed for implementation in the requester company.

While searching for design solutions students could develop a non-academic knowledge of industry and experience on solving real-life problems they could face once they graduate and obtain a job. Both university and company should benefit from this kind of academy-industry association. Due to the growing industrialization and globalization industry increasingly requests solutions from academy in different areas, like consulting, dedicated services and research. Globalization creates both an opportunity and a challenge for universities to produce proficient engineers able to compete in a flat world.

The project realization is focused on covering industry needs through the integration of graduate and undergraduate students, teacher's experience, their traditional scholarly knowledge and the use of enabling software. However, the proposal of this paper has been described from the perspective of the collaborative method.

CASE STUDY: APPLICATION TO AN AUTOMOTIVE INDUSTRY PROJECT

This section presents a case study applied to an actual automotive project in which the proposed collaborative method was successfully tested. The automotive industry has been traditionally supported by technology to automate its processes and deliver maximum productivity; unfortunately, many third party suppliers do not have a research and development department, thus they rely on academic institutions such as the university Tecnológico de Monterrey where this case study occurred.

A manufacturing industry which produces automotive steel parts needed to redesign a cell capable of the following operations: spot welding and projection welding. Currently robots feed the welding machines but the company portfolio includes pieces with diverse size, form, weight and sheet metal thickness. This kind of robots used to hold the steel parts with grippers. The current cell has robots and welding machines dedicated to each type of piece being welded because changing equipment configuration is time-consuming. To change this situation the company needs to design three new products: a spot welding machine, a projection welding machine and a reconfigurable gripper. As a consequence, a new manufacturing cell is required with load/unload zones and a reconfigurable layout able to accept different arrangement of machines.

Despite the geographical distance of roughly 300 miles (about 480 km) between the university and the manufacturing company, the project leader of the manufacturing company requested the aid of Tecnológico de Monterrey. A collaboration scheme was established following the next steps:

- The manufacturing company looked for technological support from Tecnológico de Monterrey in order to improve their manufacturing process and design new equipment. To obtain this support they had to find a teacher knowledgeable on product design and manufacturing engineering.
- Tecnológico de Monterrey had to have a course that could be adapted to this need, so professor and industrial people came to an agreement of collaboration. In this case, the course selected was Manufacturing Systems Automation (ASM) targeted to graduate and undergraduate students with a major in mechanical, mechatronics or manufacturing engineering.
- The leading professor of the selected course assembled a group of expert teachers to respond to the company needs. Professors formed a team.
- This new teaching-team scheduled the semestral course based on a POL technique to develop the manufacturing cell and equipment design project. A classroom equipped with video conference hardware was selected for the duration of the course.
- At the time of the project realization, the lead professor was in charge of the PLM Laboratory which has PLM software of the Dassault Systèmes® suite provided through IBM SUR GRANT. According to options in Table 1 above, the e-learning platform selected was Blackboard® due to its wide use at Tecnológico de Monterrey. The PDM used to promote collaboration was SmarTeam® because it is part of the PLM suite available at PLM Laboratory. Aside from the classroom equipment, other IT software tools were those of common use among

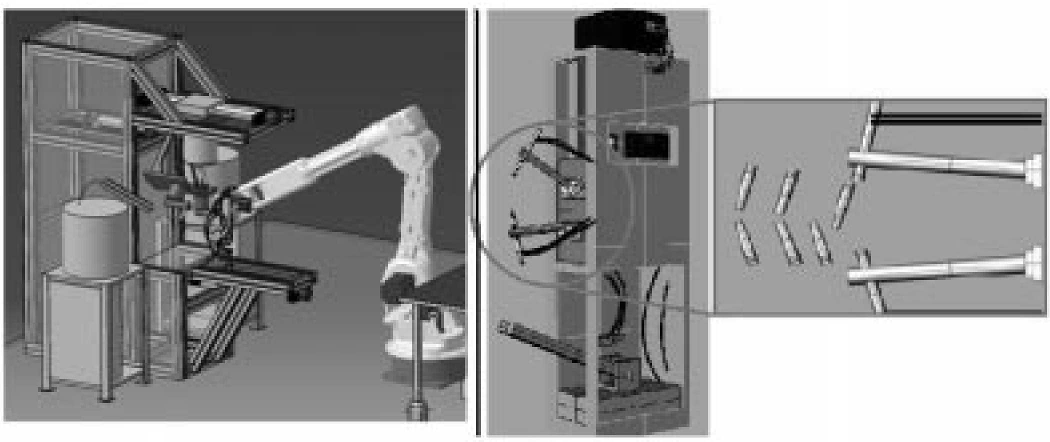

Fig. 1. Equipment designed: a projection welding machine (left) and a spot welding machine (centre) with detail on its welding clamp and electrodes (right).

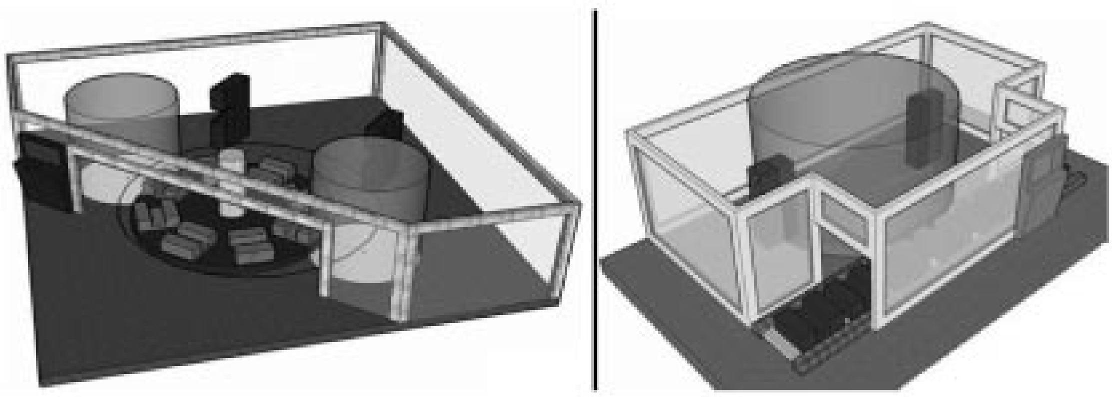

Fig. 2. Two layouts proposed for the welding cell.

internet users for email and instant messaging (freeware).

- The teaching-team and the industry project leader organized the participant students in 4 teams with specific goals. Accordingly, the whole project was divided in 4 main outcomes: 3 orientated to equipment design and 1 focused on the new manufacturing layout. Each of the designed components was responsibility of one student's team.
- As the project was carried out students received feedback from both professors and company's people to guide and correct the ongoing project. Students visited the company at their convenience during some weekends and they attended the regular course in the classroom, three hours a week for one semester.

Although each team had a particular outcome, students from different teams needed to communicate well so they could reach agreement about developing the best welding cell layout. For instance, the team focused on the layout design required details on space and machine performance from the three teams dealing with product (equipment) design. PLM digital manufacturing tools from DELMIA® suite were available. These tools were applied to support product and process development, part design and virtual manufacturing. All teams used the same file format for easy information exchange and control.

Figure 1 shows the two welding machines designed under reconfigurable requirements to accommodate a variety of steel pieces.

Figure 2 depicts two options proposed for the welding cell designed for the students. The big cylinders demonstrate the space needed by the robots to perform their loading/unloading operations. Two welding machines are represented in both proposals as vertical pedestals. The cell at the left has a carousel to carry pieces in and out of the cell. In the layout at the right part a conveyor is used for transport.

DISCUSSION OF RESULTS AND CONCLUSIONS

The completed automotive manufacturing cell fulfilled the company's specification. Solid parts were modelled and the manufacturing system was simulated to evaluate spaces and layout design. This resulted in a virtual prototype to assess automation features required initially by the client.

The combination of PLM tools with collaborative technologies provided good results for the real industry case; standard PDM systems alone would not have served the team's communication purposes.

The current globalized environment requires integration of different tools within the industry. There is a need for a collaborative tool that enables the manufacturing process to be worked and supervised by all team members (teachers, industrial project leader and students).

The collaborative teaching method proposed in this work not only allowed the goals of a real project to be reached, but it also provided other real benefits. Communication between students, professors and engineers, all of them with different backgrounds, was considerably improved with the help of technological tools, resulting in more efficient teamwork. The assignment of different tasks and responsibilities to the students helped them to get involved in the project. The students also participated in the decision making process. This active participation helped to improve the learning process since the students were more motivated to learn. Students could observe the application of theoretical concepts to a problem from the industry. Also, they develop valuable skills involved with innovation, attitude, commitment, collaborative work and self-learning along the way.

Implementation of the proposed method had a positive impact on the project realization performance, overcoming limitations such as physical distance, lack of a common social context of the partners involved and the existence of non-verbal rules (intrinsic to the company) in the communication. In addition, students were able to understand and relate to the enterprise needs, despite geographical distances.

A similar integration of concepts, tools and techniques were applied at other undergraduate engineering courses resulting in over 70 industrial projects successfully developed and implemented by local industry.

Collaborative skills from different sources are required to compete in a globalized world. The authors of this paper believe that the method we propose can be applied in other academic courses to align industry requirements with educational needs, so shortening distances between participants and adding value to design projects.

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