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Project-based collaborative engineering learning to develop Industry 4.0 skills within a PLM framework

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Abstract

Training and learning methods for engineering students, in the disciplines of product design and manufacturing, are becoming more difficult and complex since they have to integrate theoretical technical knowledge, skills in computer-aided applications (CAx) and skills in collaborative work practices. Product Lifecycle Management (PLM) tools support structured collaborative practices and CAx supports engineering content creation. Both types of software applications are key in the Industry 4.0 development. They also evolve over time, incorporate new functionalities, and change their graphical user interface (GUI), adding complexity to the learning process. Traditionally, engineering education addresses the learning of CAx and PLM tools separately, hindering a holistic learning experience to the students. This communication presents a structured integrated vision of these tools and their learning. Project-Based Learning (PBL) is proposed as a learning approach suitable to provide a learning experience that facilitates the development of Industry 4.0 skills and competences.

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Keywords: Project Based Learning, Collaborative Learning, Product Lifecycle Management, Industry 4.0 skills

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1. Introduction

Competitive markets have forced organizations to improve product development and decision-making process, and also to analyze and implement new work philosophies such as Concurrent Engineering, Collaborative Design, Integrated Product Development and Total Quality Control. All these engineering-related activities have a common focus of reducing product design and development time and costs, and increasing quality by having people collaborating more effectively.

For companies implement virtual and collaborative environments (CoE) represents a major change that requires a lot of time, plenty of effort and very strong commitment before achieving clear results [1]. Literature [2,3] shows that the main critical success factors could be summarized in the following:

- Commitment and pro-activity. Enterprises must be committed and proactive in ensuring that CoE will reduce cost, time and improve quality as well as in developing the long-term capabilities.
- Infrastructure. For virtual environments (VE), resources of hardware and software infrastructure are needed to support commercial, technical and management processes and communication.
- Knowledge and relationships. Another competitive advantage of CoE is its ability to quickly configure a solution based on its previous experiences based on available data and information.
- Trust. Virtual environment implies a loose collaboration of entities with no mandatory control over each other. Trust is the fundamental competitive advantage of virtual environments.
- Rewards. It will be necessary to create a new system of rewards for the people that will adapt to the new model of product creation value.
- Uniqueness. A successful CoE will bring to market a unique combination of skills, experiences and relationships, usually associated with a particular industry.
- Training. The most difficult success factor since there are no previous experiences in how to work in this environment.

In the case of original equipment manufacturers, regarding to infrastructures, new product design and manufacturing process definition and planning are entirely developed with computer-aided applications (CAx) and in collaborative environments supported by Product Lifecycle Management (PLM) tools [4]. Concerning to training, and focusing on engineering education, it is quite usual that these CAx and PLM tools are taught separately. A holistic education on information technologies, such as CAx and PLM, is necessary to guarantee the development of Industry 4.0 skills and competences. CAx and PLM are two of the software pillars of the Industry 4.0 trend.

The nonexistence of an integrated perspective in the engineering curriculum overlooks the necessity of teaching valuable skills in the areas of: project and workgroup management in cross-functional distributed teams, identification and resolution of design and manufacturing problems, efficient collaboration and workflow management [5].

Efforts to overcome these curriculum limitations have been made and are reported in published works [3,6]. However, this ongoing process still requires many issues to be improved. In order to draw a rational curriculum, a deep analysis of this new way of working and a definition of performances that the tools for CoE has been made. So far, PLM systems are considered the appropriated virtual and collaborative tools by the industry.

This work proposes a method to evaluate applications aiming to support the execution of collaborative practices during the development of a project. The applications Fusion 360 from Autodesk and 3DExperience from Dassault Systems are used to show the application of the method. Initially, both applications have features suitable to implement project-based collaborative engineering learning. However, from the educational perspective, benefits and implications of their use must be explicitly identified to value properly their suitability in a higher education context. This contribution is structured as follows. Section 2 provides a review of collaborative practices. Section 3 shows the proposed method and the experimental procedure. Section 4 discusses the results and section 5 shows the conclusions.

2. Collaborative practices: a cornerstone of the Industry 4.0 trend

Industry 4.0 was originally a vision encompassing the creation of global networks of companies that share their machinery, warehousing systems and production facilities, to improve the industrial processes, e.g. manufacturing, engineering, supply chain, etc., along the product lifecycle. This vision implies the collaboration of people, the interoperability of software systems and the exchange of information [5]. Therefore, from the technological perspective, integrated and interoperable software applications are key in the Industry 4.0 implementation. Similarly, from the human perspective, collaboration is key to accomplish production-engineering tasks executed in product development projects that involve many distributed stakeholders. In particular, collaboration is required in situations where several persons have to make decisions. Decisions are driven by preferences and entail socially constructed knowledge derived from human opinions and interactions. In such cases, only when there are consensual agreements among stakeholders the solutions can be adopted. However, collaboration is often taken for granted, ignored, poorly understood and accomplished in practice [2]. PLM systems provide a technological framework, where part of the interactions among stakeholders can be scheduled and documented, but collaboration processes must be defined and documented to be recreated and to train engineers, and those aspects are still very limited [7]. Project-Based Learning (PBL) can be seen as a way to recreate a limited and simple context, where students must collaborate to achieve the objectives of an engineering project and where CAx and PLM applications are technological enablers [8,9]. In the following subsections, several aspects of the collaborative work are discussed.

2.1. Collaborative Product Design and Development

Researchers and industry experts have viewed Collaborative Product Design and Development (CPDD) as the key for reducing cycle times and improving product quality and reliability. CPDD is a systematic approach to product development that achieves a timely collaboration of necessary disciplines throughout product life cycle in order to satisfy customer needs in a better way. The success of CPDD within any organization is based on the premise of how effective is the collaboration among the different work teams involved in the different product life cycle stages [10].

These product development work teams are taking on a global character that involves participant distributed geographically, even across continents. As it is widely known, in the automotive industry the design of the global car may involve teams distributed in time and space all over the world. Thereby, these distributed work teams must be supported with the effective communication and collaboration systems to ease the sharing of data and information related to design, planning and industrialization. Computer-Supported Collaborative Work (CSCW) systems offer an integration of tools and methods that support work teams collaboration and can potentially enhance the productivity and effectiveness of such groups that work collaboratively. Due to many of its capabilities, a PLM system can be qualified as a Computer-Supported Collaborative Work (CSCW) system.

The emergence and widespread use of web 2.0 offers a tremendous potential for collaborative information sharing among teams that are geographically distributed in different locations and work at different times. However, it does not provide support for structured collaboration information sharing, project/data management and control. It only provides the channel but not the solution, where distributed teams can jointly plan, monitor, manage and implement engineering projects. CSCW tries to be a solution for this problem.

There are different definitions of CSCW, depending on the nature of the application. CSCW is primarily concerned to people and computers. It is an environment where computers provide support to a group of people to accomplish a common goal or task. More concisely, CSCW is a “set of software, hardware, language components and procedures that support a group of people in a decision related meeting”.

Time and place dimensions, basically, determine the type of CSCW [1]. The different types of interaction based on these two dimensions are illustrated in the following CSCW time-space matrix (Table I). Work team interactions may take place at the same time (synchronous) or at different time (asynchronous). They may also take place in the same place (face to face) or in geographically dispersed locations (distributed).

Table 1. Computer Supported Collaborative Work systems time-space matrix.

	Same Time	Different Time
Same Place	Synchronous	Asynchronous
	Face-to-face interaction	Non-distributed interaction
Different Place	Synchronous	Asynchronous
	Distributed interaction	Distributed interaction

With this background, the next step should include a characterization of CSCW environments in order to enable Collaborative Engineering and, mainly, the performance of the software.

2.2. Characteristics of the Software for Collaboration

On the one hand, CSCW field has emerged from a growing interest on the part of software product developers interested in supporting teamwork. On the other hand, researches in various disciplines were looking for new solutions that can improve the work team productivity. During the past years, research and development in the field of human-computer interaction has shifted from single user applications (such as word processing) to group support applications such as Integrated Product Design and Development (IPDD). CSCW is a set of procedures, methods and tools that supports the work activity of a group of people working on a project, product, research area or topic with the help of computers. For instance, a brainstorming technique to generate ideas, structure them and evaluate them can be facilitated by a CSCW system. In order to ensure success, a CSCW platform should encompass the following characteristics according to the virtual and collaborative environments (CoE) introduced previously:

- Interaction in a synchronous and asynchronous way among team members.
- Coordination of the various tasks performed by the members of the team.
- Distribution to enable people to interact from remote places.
- Visualization and accessibility of data by team members.
- Data hiding, separating public and private data.
- Sharing of data, engineering drawings, applications, and so on among participants.

The preceding features set up the basis to guarantee a successful CSCW implementation. These features together provide also a complete architecture to support the decision-making process that must be aligned with industry 4.0 principles. Typically, CSCW is concerned with four issues in collaboration: Psychological, Sociological, Organizational and Technological (Figure 1). Methods and tools are seen here as enablers of CoE. In the case of technological issues, they include not only infrastructures but also software that here is known as groupware.

From our research interest, we will study the Groupware applications. These applications are the interest of the experimental and procedural process for engineering training in team working.

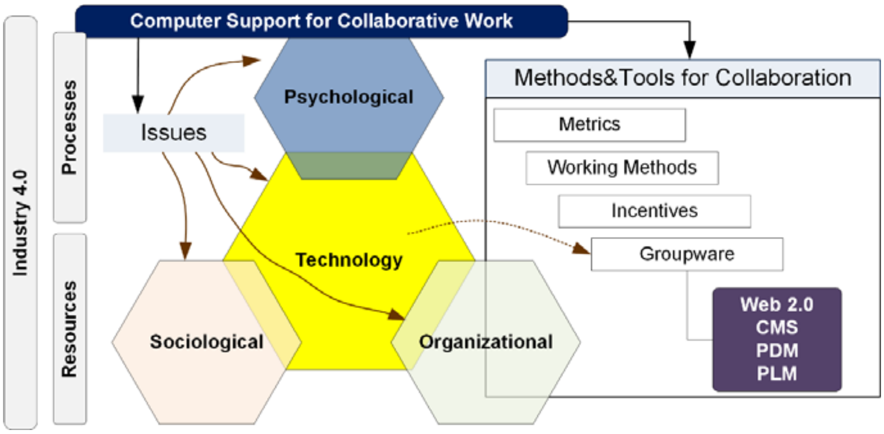

Fig. 1. CSCW Issues, Methods and Tools.

2.3. Groupware for Collaborative Engineering

The advantages that Groupware offers to teamwork can easily be drawn from the ideas previously exposed. The main reasons why organizations incorporate Groupware to support teamwork can be summarized as follows:

- Enables communication where it would not otherwise be possible.
- Facilitates communication in a faster, clearer and easier way.
- Supports communication that takes place in different places, allows organizations to cut down on travel costs.
- Allows to bring together multiple points of view, perspectives and expertise in an easy way.
- Makes possible to carry out periodical web-based meetings with multidisciplinary and geographically dispersed teams, avoiding to prepare and fulfil face-to-face meetings.
- Permits to save time and cost in coordinating work group.
- Facilitates and supports problem-solving and decision-making.

However, the efficient use of groupware goes beyond simply acquiring the software, the correct implementation and training of CSCW is key. Particularly, Groupware tools, demands knowledge on how to use it effectively to support team members interactions [11]. In the case of collaborative engineering, the most suitable platforms are the Product Lifecycle Management (PLM) tools and the formation in CSCW with them is critical for companies.

3. Methodology for Experimental Procedure

3.1. Methodology

For the experimental procedure in which we will explore the training with PLM platforms we need firsts to have a review benchmark of their performances and then try to use them satisfactorily in regular engineering courses. For this review criteria of groupware, and particularly PLM applications, several main categories of modules have been defined and within each one of them several functionalities [12].

- DATA MANAGEMENT. This category refers to every functionality related to data (file/document) management. That means attributes such sharing, importing, exporting, versioning, search, maturity states, effectivity, access rights and security.
- DECISION SUPPORT. This category refers to all the functionalities that support the decision-making process. Thereby, it will incorporate functionalities such discussion group, voting systems and surveys generator.
- PERSONAL DATA MANAGEMENT. It refers to functionalities related to personal information management (e.g. member's personal information, roles, calendar planning, etc.).
- PROJECT MANAGEMENT. It comprises the functionalities typical of project management tasks. Mainly, functionalities related to business goals, work breakdown structure definition, tasks assignation, resources allocation, workflow definition, approvals, configuration and change management, requirements, and project plan control.
- COMMUNICATION. This category refers to functionalities dealing with the communication among project members and with the project changes and status reporting. It comprises instant messaging, email, automatic changes and status reporting, notifications, news groups, virtual communities, dashboards, etc.
- Table II shows the set of functionalities included within each of the five main categories. Such functionalities are used to make a detailed characterization of each PLM application.

Once the functionalities of groupware have been defined, it is necessary to define what kind of activities and information is needed for CoE. This will help us to look for the adequate platform in order to start the test and, therefore, a preliminary benchmarking study with a defined scope. In this point, it is necessary to highlight that research is not looking for ICT-Tools, but for collaborative engineering ICT-Tools (CoE ICT-Tools) and indeed PLM platforms.

3.2. Experimental procedure

In order to handle this advanced educational problem, an action has been launched to create and share learning experiences. Within this action, two parallel projects are being designed and are being executed, aiming to promote the use of CAx-PLM technologies in collaborative engineering education between four universities. The implementation of the two practical CAx-PLM experiences will be conducted in manufacturing related courses.

Table 2. Proposed CSCW groupware categories and functionalities for characterization.

Category	Functionality	Description
DATA MANAGEMENT	*File sharing / Management* *Version Control* *Search system* *Role based access control* *Access Control/Security*	These set of functionalities includes all the plications related with electronic data of documents related to CAD/CAE/CAM and others. They deal with how to give access to them to the correct user.
DECISION SUPPORT	*Discussion Forum/group* *Voting system* *Survey and feedback*	Applications for interaction between the members of the team, synchronous or asynchronous, for decision-making.
PERSONAL DATA MANAGEMENT	*Contact list/manager* *Group Calendar*	Relation of professional data inside and outside the organization and meeting tools
PROJECT MANAGEMENT	*Project planning* *Milestone / Workflow* *Tasks Reminder* *New events e-mail notification*	Collaborative process need tools for planning and resources assignment. Theses apps must enable the time scheduling of the project and the coordination of tasks while creating digital documents with CAx tools
COMMUNICATION	*e-mail / News group* *Web Conferencing* *Instant messaging /chat* *Audio conferencing* *Whiteboard*	Communication tools and exchanging of data, information and ideas. For these functionalities it is not necessary to have them embedded in the platform since there are many of them free but the problem is to synchronise them with the whole process
MISCELLANEOUS	*Reporting* *Time card system* *Integration with other system* *Personalised profile*	This set of functionalities includes different applications that could be used during collaboration. Today the trend is to have a platform based on web 2.0 that has a similar aspect to social networks.

These courses are focused on teaching fundamentals of how to work in manufacturing engineering with CAD/CAE/CAM and PLM systems in a collaborative way. The key element in the design and deployment of both experiences is the CAx-PLM software framework to be used that is applied to commercial tools to explore the proposed categories and functionalities (Figure 2). Here Fusion 360 from Autodesk and 3DExperience on the cloud from Dassault Systemes are being tested [9].

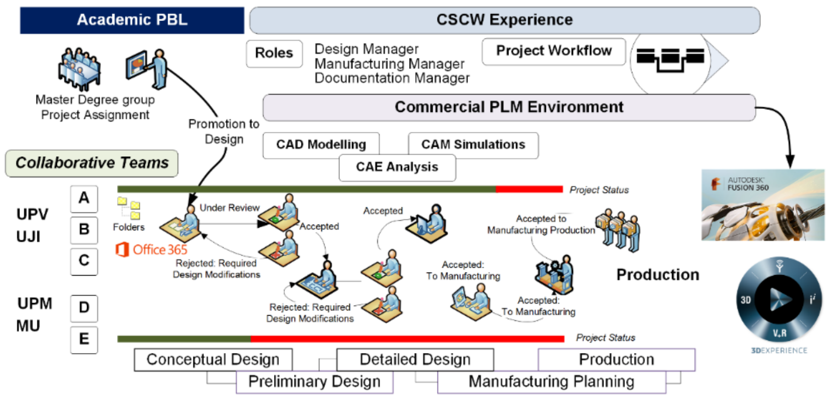

Fig. 2. CSCW Project Based Learning with PLM platforms.

These software's frameworks provide a wide range of apps for unstructured collaboration, structured collaboration, information intelligence, and engineering content creation and management. Both academic projects have implemented the Project Based Learning (PBL) concept [3,9] but they make use of a different approach in terms of the collaboration apps and procedures as they have test initially two different platforms. However, in both cases the students are learning by practicing through activities such as 3D modeling, 3D tolerance analysis, 2D drawings creation, component analysis and simulation, and material removal processes definition and simulation.

4. Results and Discussion

Once the environment is arranged, the kickoff of the projects have been launched and all the collected information has been processed to enrich the academic training oriented to future engineers. Since the platforms are slightly different, we have had diverse approaches and the results differ in the percentages achieved of the estimated aims.

For the Fusion 360 experience, we have found that the first barrier to overcome is to plan the project. Students are used to work directly on the CAD tool without preparing the work. The learning curve of the apps in this platform is quite easy, however it is difficult to get students to work in parallel on the web (Figure 3). Another advantage is that all the CAx apps are integrated and there is a possibility of revision including from the tablets or smart phones.

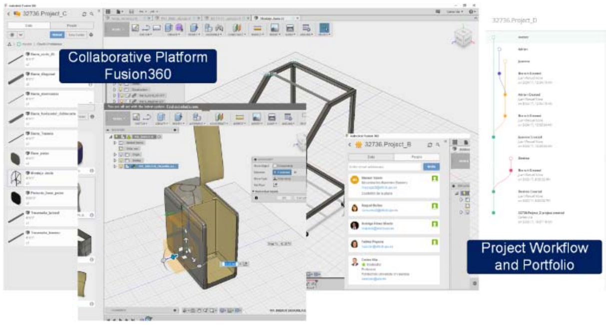

Fig. 3. Partial results with Fusion360 platform.

The second PBL academic practice is based on 3DEXperience (Figure 4). With all the partial results, we have tried to do an initial benchmark of the platforms to discover their advantages and the way of applying them in the academic experience (Table III).

Table 3. Initial benchmarking of tested PLM platforms

	Functionality	FUSION 360		3DEXPERIENCE	
DATA MANAGEMENT	*File sharing / Management*	Y	Basic control of documents integrated with CAx. Access to data is based on project permission not in roles.	Y	Complete platform for product data management based on ENOVIA. Very complex system to customize and to use, need deep learning.
	Version Control	Y		Y	
	Search system	Y		Y	
	Role access control	N		Y	
	Access Control/Security	Y		Y	
DECISION SUPPORT	*Discussion Forum/group*	Y	Easy to use app for live review of CAx models and analysis.	Y	There are different apps for CAx reviews and comments addition.
	Voting system	N		N	
	Survey and feedback	N		Y	
PERSONAL DATA MANAGEMENT	*Contact list/manager*	N	Web calendar on web platform.	Y	Business intelligence apps.
	Group Calendar	Y		Y	
PROJECT MANAGEMENT	*Project planning*	N	This version has not a project manager app but a branch manager and milestones for parallel work in the same object.	Y	All the functionalities are included. Project manager has to map the entire collaborative plan to the platform for easing the use.
	Milestone	Y		Y	
	Workflow	N		Y	
	Tasks Reminder			Y	
	New events e-mail notification	Y		Y	
COMMUNICATION	*e-mail*	N	In the web content mgmt. system, there is a wiki app, which can be used as news group and to make instant comments on models.	Y	Although communication services are solve with third part apps, the platform includes a set of customizable dashboard to show all of them.
	News group	Y		Y	
	Web Conferencing	N		N	
	Instant messaging /chat	Y		Y	
	Audio conferencing	N		N	
	Whiteboard	Y		Y	
MISCELLANEOUS	*Reporting*	Y	Each CAx app has a report generator.	Y	The main aspect is the integration with Manufacturing and Industry 4.0 apps.
	Time card system	N		Y	
	Integration with systems	Y		Y	
	Personalised profile	Y		Y	

This project is planned but its execution has been delayed due to temporary unavailability of the cloud service. The collaborative scenario recreates a manufacturing outsource scenario with Design for Manufacture gate reviews. Thus, under lecturer supervision, UPM manufacturing students will review, design and simulate the manufacturing process, and estimate the costs of MU's designs, which include students' 3D assembly models with tolerances and 2D drawings of a mechanical product. Therefore, the scenario is expected to naturally foster the usage of CSCW. Finally, the part manufacturing will be outsourced to get an industry assessment of the cost estimates.

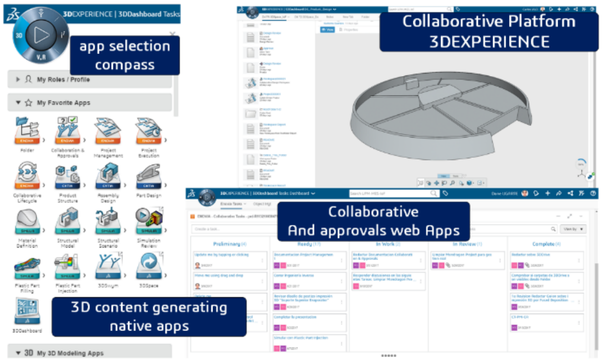

Fig. 4. 3DEXPERIENCE on the web partial results.

5. Conclusions

Lessons learned from comparing the two collaboration experiences are allowing us to identify scenarios where different collaboration approaches can be applied and translate them to engineer's training. Architecture, structure and templates of each learning project are different but there is a baseline that can be shared in each learning project. The students output and feedback on each project are helping to correct the scope of the project in this kind of PBL, since the learning curve is different and depends on the engineering discipline and the platform. Current practices have showed the need to define templates and collaboration procedures to make an appropriate and efficient use of the apps and to accelerate the students' learning curve. This aspect is critical, over all in complex PLM environments, where available functionalities are extremely large and students are unable to identify which capabilities use and for what.

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