Accelerating the adoption of Industry 4.0 supporting technologies in manufacturing engineering courses

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Abstract. Universities are one of the fundamental actors to guarantee the dissemination of knowledge and the development of competences related to the Industry of the Future (IoF) or Industry 4.0. Computer Aided (CAX) and Product Lifecycle Management (PLM) technologies are key part in the IoF. With this aim, it was launch a project focused on Manufacturing and partially funded by La Fondation Dassault Systèmes. This communication presents a review on CAX-PLM training, four initiatives already in place in universities participating in the project, the project scope, the approach to integrate with the industrial context, the working method to consider different competence profiles and the development framework.

Introduction

In addition to research programs, since a few years ago several countries, Germany, Italy, France, USA, etc., has launch initiatives dealing with the implementation and adoption of Industry 4.0 or Industry of the Future [1,2,3]. In Spain, the program named 'Industria Conectada 4.0' was launched in 2016 and it is structured into four main lines of action [4]:

- Guarantee dissemination and development of knowledge and competences on Industry 4.0 (I4.0).
- Promote multidisciplinary collaboration.
- Boost the development of I4.0 enabler organizations.
- Promote actions to facilitate the adoption of I4.0 technologies.

Training on Information and Communication Technologies (ICT) is needed to guarantee knowledge and competence development in the current and future generations of technicians and engineers. Forecasts about the European labor market point to a high lack of professionals with knowledge and competences on ICT within the production environment [3]. This situation is quite similar to the one in the early 80s, when the adoption in the manufacturing companies of Computer Integrated Manufacturing (CIM) technologies was taking place [5].

Several studies highlight also the training and learning needed in engineering studies to facilitate the professional development in an industrial context characterized by: globalization, competitiveness, multiculturalism, multidisciplinarity, collaboration, and intensive use of ICT technologies in the development and execution of engineering functions [6]. Among the identified key elements, linked to the I4.0 context, highlight the following ones: knowledge and competences on computational and simulation technologies, understanding of the product lifecycle phases, understanding and competences in planning and management of projects, and competences in teamwork [6]. Beyond specific technological knowledge, the competences needed in an I4.0 context are not very different from the ones already identified by several organizations when characterizing the future in engineering education [6,7].

In this context, and similarly to what happened with the Computer Aided technologies (CAX) [8], universities are one of the key agents to guarantee transfer of knowledge and development of competences in the I4.0 technologies. In particular, teaching staff has a role of students' enabler; students are future engineers, who will develop their professional career in an I4.0 context. Similarly to what happens in the industrial context [3], in the educational context, there is a need to keep personnel up-to-date with the I4.0 technologies, which implies evolving to acquire new knowledge and competences. Such evolution depends on the personnel's current knowledge and on the objectives that each educational organization defines within its action plan. Therefore, there is a need to define an initial training phase, where theoretical content and industrial software applications, which support the I4.0, are coordinated and harmonized. Theory and practice are the key elements to guarantee knowledge and competence development.

With that aim, in 2016 the project named 'Accelerating the adoption of Industry of the Future (IoF) supporting technologies by Spanish universities'; was launched. It is an educational project, with a focus on manufacturing related competences and partially funded by La Fondation Dassault Systèmes. The project implies teaching personnel from twelve Spanish universities: Cádiz, Cantabria, Jaén, Jaume I Castellón, León, Mondragón, UPC, UPM, UPV, Sevilla, Vigo and Zaragoza; three French universities: ENI Metz, EC Nantes and U. Versailles S-Q-Y; and one Italian university: Politecnico di Milano. The project timeframe is four years and aims three main objectives:

- Accelerate the adoption of learning practices and competences in I4.0 technologies, in particular, related to CAX-PLM in the manufacturing area.
- Harmonize teaching practices and learning materials, using a collaborative development process, which facilitates a better and more efficient creation. At the same time, it should allow creating an international community of educators and instructors with a similar motivation.
- Improve the students' learning experience, their digital competences in I4.0 technologies and as a consequence, their employment perspectives.

This communication shows first a brief state of the art in the project domain. Then, it discusses the collaboration with the industrial environment. Next, it shows the current situation, by means of four cases developed in four universities that participate in the project, and the current limitations. Finally, it presents the development environment considering different competence profiles, and a first list of the expected benefits derived from the execution of the project.

Brief state of the art about the education in CAX-PLM technologies

CAX-PLM systems are a key support of the I4.0. They allow creating and managing a source of true data sets (e.g. product digital models) that feeds several processes along the product lifecycle [9,10].

As it is mentioned by Dankwort et al. [8], students receive training in technologies dealing with product digital models creation, i.e. CAD systems, which is conditioned by the historical evolution of such systems. Traditionally, training starts with the creation of 2D representations, sometimes even manually created and paper based, then 3D modeling is introduced, to continue with parametric and variational design modeling (CAD). In parallel, training on Computer Aided Engineering (CAE) applications that make use of numerical methods (e.g. finite elements) can be conducted. Finally, to address the management of engineering data created with such a CAX applications, the Product Data Management (PDM) or Product Lifecycle Management (PLM) systems are presented to the students. Examples exist, where students are trained on CAX-PLM technologies in an integrated way [11,12]. It should be also pointed out that training on CAX-PLM systems is linked to different professional profiles. Each professional profile requires knowledge and skills on specific applications that conforms the wide spectrum of tools included within the commercial CAX-PLM systems [8]. It should be also keep in mind, that during the students' training, in addition to learn the use of specific applications, the priority must be to understand and assimilate the set of reasons that makes the CAX-PLM systems a basic and fundamental tool to conduct the engineering tasks in the present industry [13].

Together with the CAX-PLM systems, Web 2.0 communication tools (discussion forums and wikis) are also used as learning means [14], and as unstructured collaboration tools in the application of project-based learning methods [15]. Other applications, such as voice and video communication via Internet and cloud storage services are also used in collaborative project-based learning methods [16]. The development and use of learning environments on the cloud, applied to design and manufacturing are also reported in the literature [17]. In particular, this environment comprises commercial 3D CAX applications, together with a learning management system for the synchronous and asynchronous communication between students and teachers [17].

At the pedagogical level, a significant amount of the higher education on CAX-PLM systems is conducted following the learning model based on projects, i.e. Project-Based Learning (PBL) [11,12,13,18,19,20,21,22].

The use of the PBL model implies the definition of a project, along which a team of students acquires and develops knowledge and competences. The collaboration with the industry is highlighted as one of the main factors when defining projects that provide a relevant learning from the perspective of employability [13]. In such a context, is where it is framed the collaboration with the aerospace industry proposed in this work.

Collaboration with the aerospace industry

Currently, the main objectives of the aerospace industry are directly linked to industrial projects framed within different European 'Advanced Manufacturing' initiatives, e.g. Clean Sky, Factories of the Future, Usine du Futur, Industry 4.0, High Value Manufacturing Catapult, and a big variety of regional programs promoted in different counties. The European industry in general and the aerospace industry in particular is immersed in those projects and requires engineers with competences and specific practical training in new digital technologies. In that direction, the collaboration between university and company proposed in this project allows integrating experiences, practices and industrial information to facilitate that the theoretical and practical training is better aligned with the industrial needs.

The competences that the aerospace industry demands in relation to the CAX-PLM systems were taken as a reference in the objectives of this project, and they are summarized as follows:

- Skills of using PLM systems, in particular 3DExperience®, a 'de facto' standard system in the aerospace sector and widely used in the automotive and other industrial sectors.
- Knowledge of methodologies and tools for Virtual Manufacturing using 3D models and virtual simulation techniques. Including methods, processes and tools for the adoption of the Digital Factory and the industrial Digital Mock-Up (iDMU).
- Knowledge of methodologies and technologies to exploit the digital information in the manufacturing plants using I4.0 techniques: augmented reality, virtual reality, Internet of Things (IoT), etc.

The European aerospace companies hire engineers who mostly graduate in the main engineering schools located in their area of influence. That is why the support from the industry to those schools is quite important. To do so, a set of actions must be established and developed along a project:

- Industry and academia must share a midterm and long-term view on educational aspects.
- Considering geographical proximity, a sponsor must be identified in the company.

- Industrially relevant technologies must be used both for the current and future situations.
- Industry must understand and benefit of securing a connection between its needs and the studies and practical work of possible future employees.
- Academy and industry must facilitate the creation of an industrial culture within the higher education studies and the transfer of knowledge between both.

Current educational cases dealing with CAX-PLM technologies in Spanish universities

This section shows four cases of universities participating in the project. The objective of this section is to illustrate the diversity of applications used (e.g. CAX, PLM, communication, storage, unstructured collaboration), of involved disciplines (e.g. design, geometric modelling, planning and modelling of processes, simulation, prototype creation), and of the competences to develop (e.g. collaborative teamwork, innovation, project management and planning, 3D virtual modelling and simulation).

Case of the University Jaume I of Castellón. This case addresses the development of collaborative projects in the Master Program of Design and Manufacturing. This is one of the first academic experiences in Spain, at Master level, where the academic projects involve the use of CAX-PLM applications. The educational model is based on projects or module assignments that integrate several courses. This case comprises a training module on the methodological use of CAX applications, integrating the product design and development process with a PLM application to support the collaborative teamwork. The teaching methodology is based on the creation of a project dealing with the design, analysis and manufacturing planning of a product or machine. The starting point is the definition of the product lifecycle and the project plan with the work breakdown structure.

The basis is a framework model that comprises the definition of the following elements. The categories of objects to be managed along the project, for instance, types of documents (e.g. *.docx, *.pdf, *.xlsx, etc.) and the types of CAX objects (e.g. 3D parts, 3D assemblies, 2D drawings, numerical control code). The information flow is also defined in a model that comprises phases and approval gates. Additionally, the model comprises teams, roles and rights. This framework model can be used as starting point independently of the PLM software platform or systems to be used [11,19].

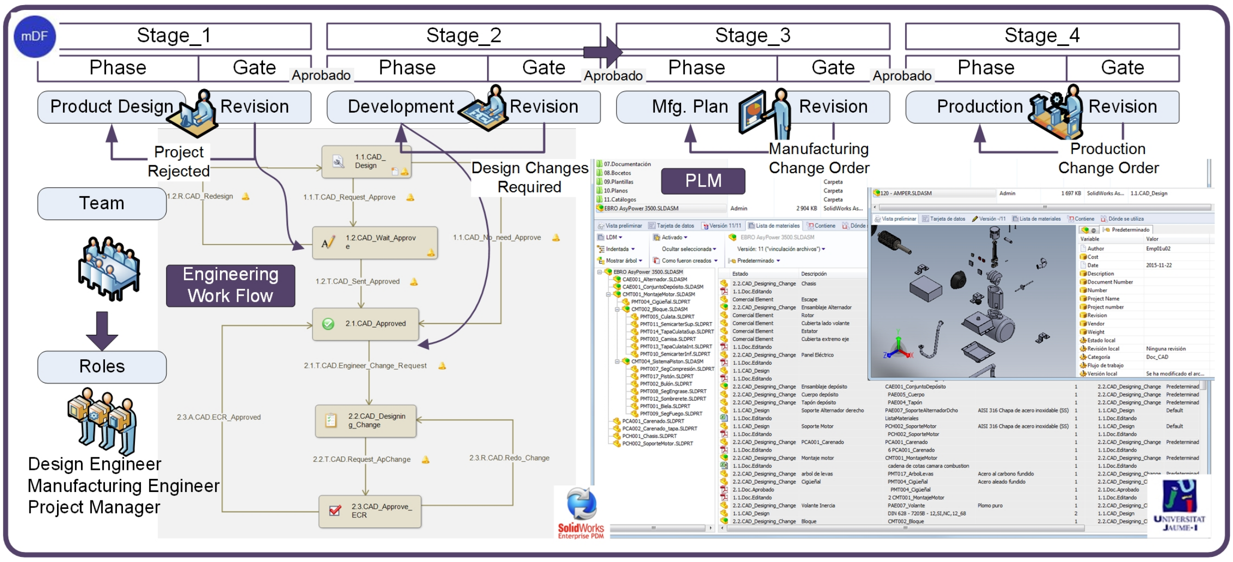

Fig. 1. CAX-PLM learning framework model in U. Jaume I

In particular, the current implementation is built around PDMWorks Enterprise® as collaborative and integrating platform. Solidthinking Evolve-Inspire® is used in the conceptual design tasks.

SolidWorks® is used for 3D solid modeling tasks and engineering analysis tasks (CAE). SolidCAM® is used for the planning and simulation of machining processes. Fig. 1 shows a top-level view of the learning framework model.

Once the framework model is defined, and the software tools are implemented and configured according to the framework model, the next stage is to launch and execute the team projects. During the execution stage, the academic personnel must coordinate the learning experience of the students in terms of modeling of parts and assemblies, both at the conceptual and detail level, together with the engineering analysis. The practical case deals with the redesign of an existing machine or industrial product. Each team uses the provided CAX software tools to execute the engineering tasks and manage the project and their teamwork with the PLM system. The tutors can monitor in real time the progress of each project, team and student individually. As final deliverable, each team must create a project report and give a presentation showing the achieved results and objectives.

Case of the Mondragón University. This case applies as basic learning approach the use of active methodologies, and its continuous, global and competence-based evaluation. Each semester, students are grouped into teams. Students start with the acquisition of basic contents related to each competence by means of lectures, practical classes on the support technologies (e.g. CAX applications) and interactive and dynamic activities during classes with the support of Moodle®, a learning management system (LMS). Fig. 2 shows the learning framework. Once the students acquire certain basic knowledge, the lecturing staff of each semester propose a problem, which integrates all the competences addressed during the semester, to be solved by the students. Therefore, the learning methodology is named as Problem Oriented Project Based Learning (POPBL) [20,23].

The CAX technologies used in all the studies are commercial applications used in the industry:

- CAD: SolidWorks®, Rhinoceros® and NX®.
- CAM: GibbsCAM® and NX CAM®.
- CAE: SolidWorks® Simulation, Simulia® and ANSYS®.

It is relevant to point out that the students acquire, in an integrated way, the competences on design, analysis and manufacturing together with its corresponding support technologies.

Along the execution of the POPBL project, the students acquire specific competences on the support technologies, for instance on product data exchange by means of generating standardized format files (e.g. ISO 10303 – STEP) and on management of file versions. The data translation and neutral files generation is carried out by using the translation capabilities provided by the commercial CAX applications. The file versioning is done manually following a predefined practice.

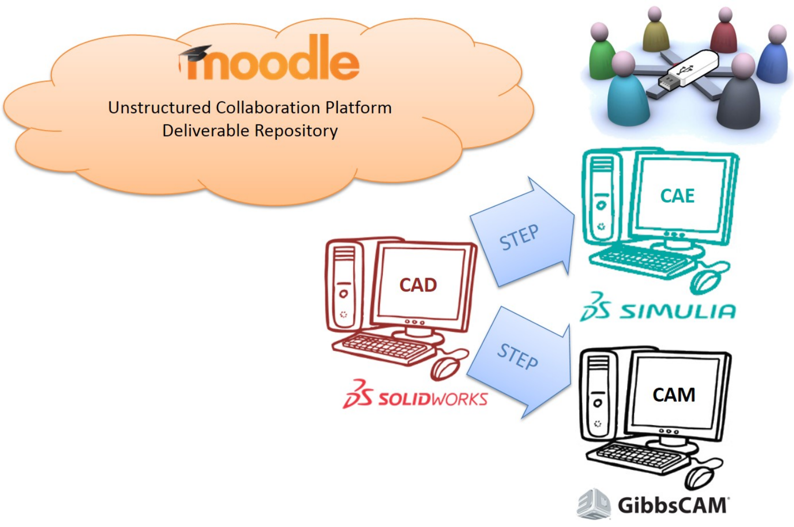

Fig. 2. CAX technologies learning framework in Mondragon Unibertsitatea.

Additionally, the students develop the competences related to project management, for instance, files sharing within the team members and tutors, team members with different roles, management of tasks and resources, oral and written communication both structured and unstructured, project review meetings, creation and delivery of the project deliverables. Different means, e.g. USB memory sticks, email, WeTransfer®, Google Drive® and DropBox®, are used to carry out the sharing of files. The allocation of roles, tasks and resources is designed together with team tutor, and this is done at the very beginning of the POPBL project. The monitoring of the project is conducted on a weekly basis and by different means and formats. Unstructured or informal communications do not leave any record. The formal communications are conducted during the project review meetings. The review implies oral communications with the tutor and academic experts, and the use of different software applications to show the project progress. These monitoring meetings are schedule every third of the project duration. The formal written communication is a final project report, the deadline for this deliverable is the last day of the project and it is submitted in Moodle®. All the files generated using the CAX applications, along the POPBL project execution, are delivered in Moodle®, which is used as the project deliverable repository.

Case of University of Cádiz. The Higher School of Engineering hosts most of the Degree and Master Engineering studies within the Industrial specialty and/or industrial sector related such as the Aerospace specialty. The I4.0 support technologies dealing with CAD/CAM/CAE and PDM/PLM systems are within the scope of the Manufacturing Processes Engineering Area.

The academic education of these technologies is currently more related to the typology of subjects than to the development of projects with multifocal objectives. The reason for this is the difficulty of coordinating and allocating the right means to provide optimal learning conditions to students enrolled in different studies and even in different academic year, which causes having different knowledge levels.

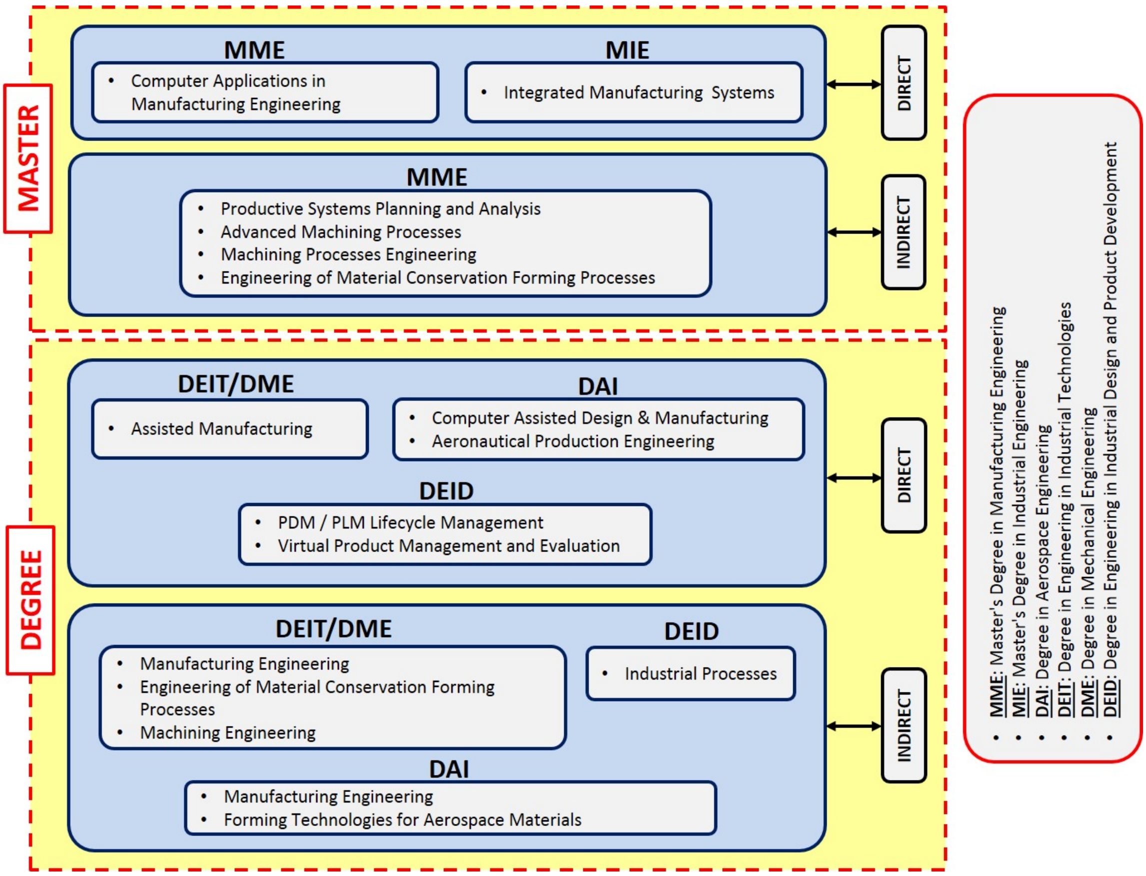

Fig. 3. Overview of the CAX-PLM technologies usage in the U. of Cádiz.

Depending on the content and activities of the subject, two categories are defined. The category named as Direct, implies that the subject content is supported by those I4.0 technologies. The category named as Indirect, implies that the subject requires those I4.0 technologies only as a complement to its content. Fig. 3 shows the Degree and Master courses and their link with the CAX-PLM technologies.

The methodology of application is very different depending on the category where each course is framed. Hence, in the indirect category courses, these technologies serve as practical working tools. Basically, students have a certain degree of freedom in the use of the tools, and there is no specific training on best practices to use the tools. In this case, the CAD software application can be CATIA V5® or any other software with similar capabilities, e.g. SolidWorks®. When considering manufacturing planning and simulation, there are two levels: machining process level and machining physical simulation level. At the machining process level, the applications comprised within CATIA V5® are used. At the machining physical simulation level, a specific CAE tool, named Third Wave®, is used. General-purpose CAE tools, such as ABAQUS®, are used in specific courses of the Master program.

In the direct category courses, due to the links with the aerospace industry, the solutions from the software vendor Dassault Systèmes are used. In this case, a project-based working methodology is used [24]. However, the ideal solution would be to develop integrated projects or master programs, applying a hierarchy of roles, for this approach a software infrastructure different from the current one is need. In that sense, the 3DEXPERIENCE® platform would be the solution. That would facilitate the realization of projects where inter-study teams could be created, with predefined hierarchies, which in one semester could conduct a multidisciplinary project. This would eliminate some of the current barriers, and would allow incorporating academic personnel from partially related areas of knowledge.

Case of the Polytechnic University of Madrid – Industrial Engineering School. Currently, in the Degree and Master studies, only different CAX applications are used (e.g. Solid Edge®, SolidWorks®, CATIA V5®, NX®, Flexsim®, etc.) in different courses. Therefore, there is no an integrating solution, based also on the use of a PLM system, that allows students developing a multidisciplinary collaborative project. This case focuses on the course named Design of Manufacturing Systems. This course has 6 ECTS credits and is lectured in the fourth academic year of the Degree of Engineering in Industrial Technologies.

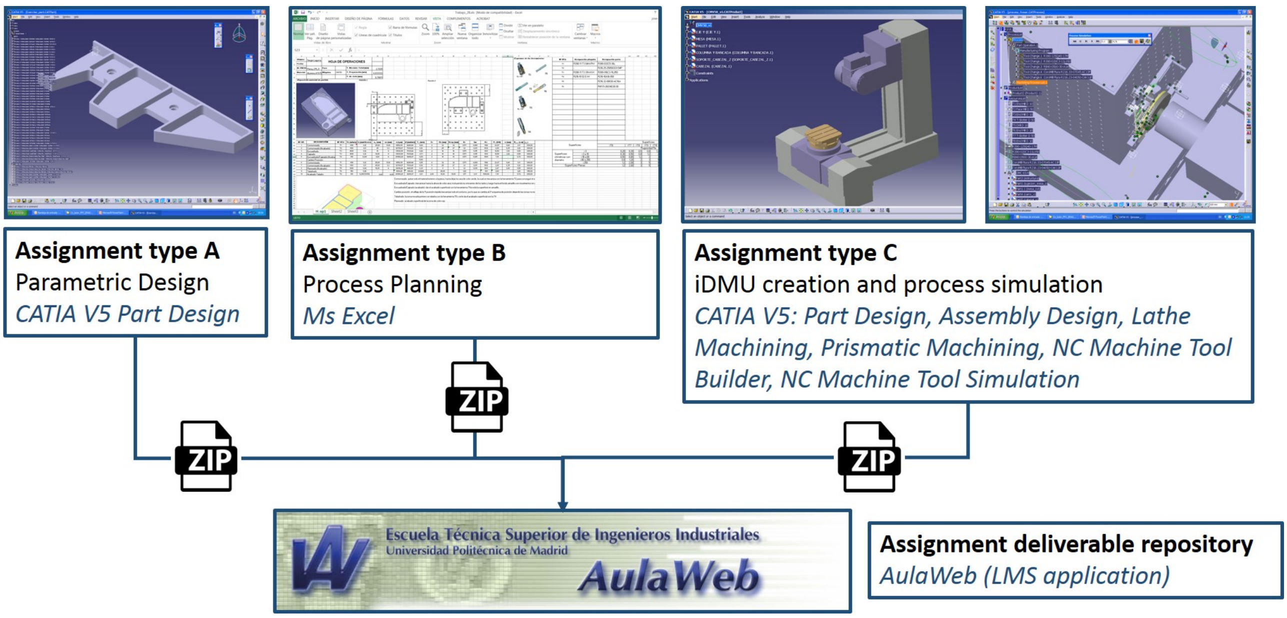

Fig. 4. Example of assignment results and context in the UPM case.

The course focuses on Computer Aided Manufacturing (CAM). It is structured to guide the students from the numerical control (NC) programming, to the Computer Integrated Manufacturing (CIM) concept, going along a set of key concepts, such as the need of a continuous flow of information between the phases of design, planning and manufacturing, the need of managing engineering data and therefore of PLM systems, and virtual manufacturing. The practical works are assigned individually to each student and they are oriented to develop competences dealing with the creation of the iDMU. Students carry out six practical assignments, where they use three software applications: CATIA V5®, Ms EXCEL® and AulaWeb (see Fig 4).

The first two assignments comprise the 3D parametric/variational design of two parts that will be manufactured by material removal processes (e.g. milling, drilling, and turning). Students create the parts using CATIA V5®. The two following assignments comprise the definition of the machining process of each part, including: phases, operations, tools, fixtures and cutting conditions. As constraint, basic information about the NC machines where the parts could be machined. This process planning works are documented by means of phase and process sheets created with Ms EXCEL®. The third set of assignments comprises the use of CATIA V5® modules dealing with NC machining (CAM modules), to complete the definition of each part iDMU. An iDMU includes the part to be manufactured, the initial or stock material, the processes to execute and the resources (machine, tooling and fixtures) needed. Each process specifies its type, fixture to be avoid, geometry of the part limiting the areas to machine, machining strategy, cutting tool, cutting conditions, approach and retract movements of the tool. During the creation of the iDMU each student simulates the defined machining process plan and accepts or modifies it according to the obtained result. To simulate the machining environment, each student must create a 3D model of the NC machine and the 3D models of the corresponding fixtures. The NC machine model is created using the NC Machine Tool Builder module. The NC machine model comprises the machine architecture and kinematic data, a simple virtual model that allows simulating the machining, showing the movement of the main machine axis. The virtual machining environment shows the 3D models of the NC machine, the initial part, the finished part, the fixtures and the movement of the cutting tool during the execution of each operation. For each assignment, each student delivers a zip file using the web-based application AulaWeb (LMS). The zip file must contain all the data and files so that the tutor can reproduce the result of the work.

Needs and limitations

This section shows an integrated view of the needs and limitations observed in the four cases presented in the prior section.

- The use of the PBL model demands a prior definition of the project, relevant from the industrial perspective, but adapted to the learning context and timeframe.
- The use of the PBL model, in a PLM collaborative environment, demands implying academic staff from different knowledge areas, prior to the project execution, they must learn or be familiar with the working method and the PLM system.
- The use of a PLM collaborative working system requires a prior work to setup the system, including system configuration and access management.
- In those cases where an online PLM collaborative system is not used, then a LMS system is used instead (e.g. Moodle). This solution impedes training students properly on collaborative projects management and execution, limiting the competence learning.
- The first training stages on PDM or PLM usage require an additional motivation; the utility of these systems is recognized along the execution of the project and as the data to manage increases (e.g. 3D models, simulations, analysis results, etc.).
- The lack of a PLM system limits the students' training on competences, since they do not have access to a collaborative working environment, currently essential in midsize and large companies with multi-location.

- The lack of a PLM system hampers the monitoring of the project, the access to the project data and the trace of changes, both to students and tutors.
- The lack of a structured management of CAX files versioning, leads to review of old files and delivery of obsolete files by the students, causing inefficiencies, frustration and negative learning experiences.
- In general, the current licensing management model of many CAX-PLM applications limits the access and the autonomous work of students and tutors.
- In any of the cases, the CAX applications and a PLM client application, together with its corresponding help content, had to be installed in the students' computers. This situation demanded to give a support service that frequently exceeds the capabilities of the academic personnel involved.

Project learning proposal: PBL methodology with 3DEXPERIENCE® and PL'EXP

The platform '3DEXPERIENCE® on the cloud' from the software vendor Dassault Systèmes, in addition to the CAX-PLM applications and the data repository, integrates applications for unstructured collaborative work, instant messaging, wikis, dashboards, social networks analysis, data intelligence and analysis, etc. This platform allows applying the PBL pedagogical model and additionally training students in an industrial centralized collaborative working environment and accessible via Internet [25]. To complement this commercial platform, it is proposed the use of a learning web portal, where students can perform auto-learning tasks. Peer Learning EXPerience (PL'EXP) is the name of the learning web portal. This portal provides access to specific learning material and courses developed by an international academic community of 3DEXPERIENCE® users and trainers with the objective of being shared and use in higher education Degree and Master Program courses. Both students and academic staff can have access to the portal whenever an Internet access is available. PL'EXP portal is a development of Dassault Systèmes using Moodle®, a well-known LSE platform. The Fig. 5 shows the structure and the main user interface of the propose environment.

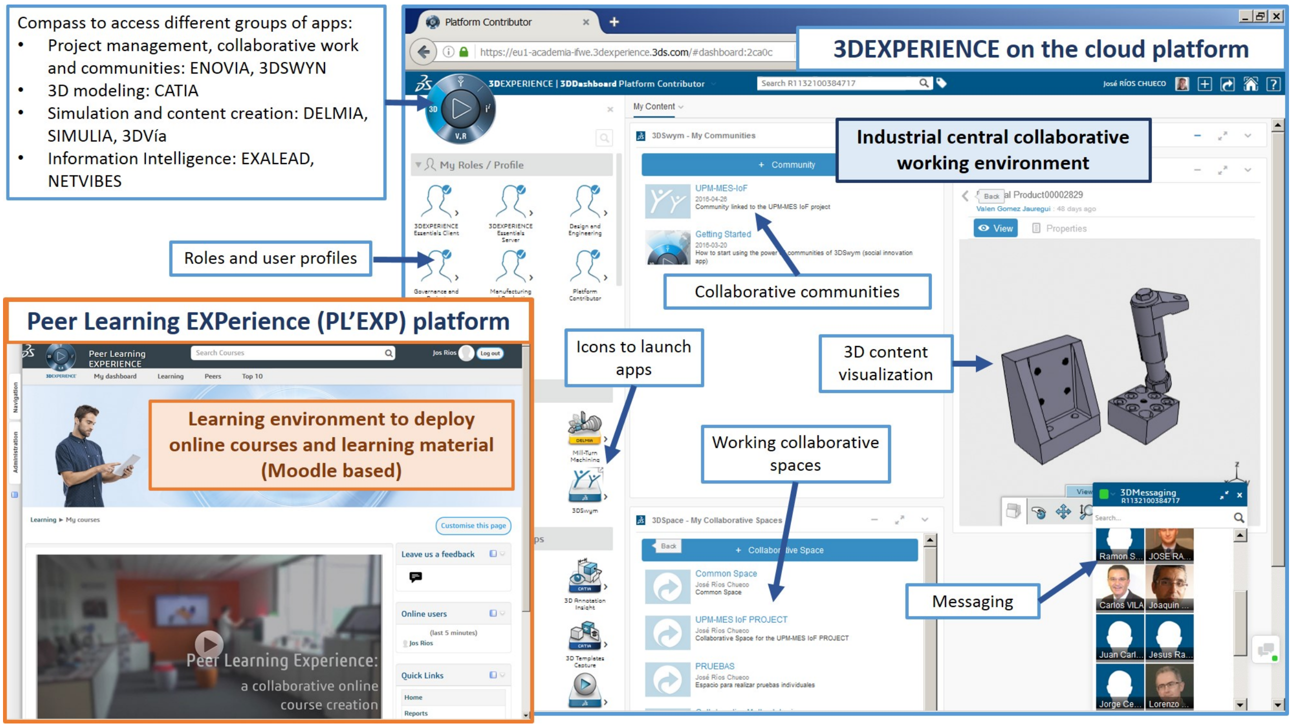

Fig. 5. Proposed learning platform: 3DEXPERIENCE® on the cloud and PL'EXP.

The methodology proposed in the project is based on the collaborative creation of learning material that will be available within PL'EXP. The learning material will be complementary to the software help and to the classroom education provided by the academic staff in their respective universities (blend learning). It will allow formalizing the learning content in the Manufacturing domain and accelerating its creation and maintenance. The priority in the creation of the learning material is based on the priority assigned to a set of professional roles identified by the industry, e.g. project manager, requirements manager, mechanical designer, tooling designer, NC programmer, robotic system programmer, plant layout designer, process planner, times and process flow analyst, assembly process simulator, etc. The use of the PBL methodology allows assigning roles to the students that constitute a team, and therefore generating profiles with a certain level of differentiation in terms of theoretical knowledge and competences on software applications. All the students share the competences on collaborative teamwork and on the PLM system used for it.

This learning proposal should provide the following general benefits:

- Harmonization of educational practices, integrating content based on profiles, both in manufacturing and in collaborative teamwork. The content is developed into self-learning courses, which are available both to students and to academic staff from any discipline, facilitating the virtual learning.
- Standardization of the academic working flows in projects dealing with design and manufacturing. Facilitating access, content integration, management and evaluation of the assigned projects and synergies between the academic staff involved.
- Structured and unstructured collaboration is possible using a single platform.
- Development of academic projects that are closer to the industrial world, with the participation, without geographical limits, of academic staff and professionals from the industry.

Conclusions

The literature shows the relevance and need of accelerating the education and training on CAX-PLM technologies as a key support of the Industry 4.0 concept. The current state in the academic use and education of those systems, showed in the case studies, is a representative sample of the situation in the technical universities in Spain. A proposal based on use of a system on the cloud, which comprises an integrated collaborative CAX-PLM environment, and promoted by a set of universities having collaboration with the industry, could be the solution to many of the limitations identified in the current situation.

The first tests conducted on the platform usage has provided an insight to estimate the benefits that would be derived from its implementation in an educational context. It must be kept in mind that 3DEXPERIENCE® is an industrial software platform that allows executing engineering projects in a collaborative working environment on the cloud. This means that it will not be possible to use in an academic context many of the capabilities of the platform. The combination of this industrial software solution with the collaborative learning web portal is a new approach within the CAX-PLM educational and training context. Future communications will allow showing specific results obtained along the project execution.

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