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Collaborative Product Development Experience in a Senior Integrated Manufacturing Course*

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In the new scenario of global competitiveness, companies are forced to outsource and distribute product manufacturing in order to minimize costs and delivery times. Hence, engineering education must encourage students to work according to this trend by taking advantage of recent developments in Product Lifecycle Management systems (PLM). We have reviewed past educational efforts to educate future engineers with these skills, and the CAX techniques applied in education to achieve them. We also present a new PLM experience conducted in a senior Computer Integrated Manufacturing (CIM) course for graduate students, where a collaborative product development project was carried out. Through the project experience, the students acquired abilities related to design and manufacturing in a collaborative environment, using CAD/CAE/CAM and PLM software tools. The project let the students learn by practicing through activities such as 3D design, drawings, plastic injection analysis, cutting-tool and fixture selection, cutting parameter selection and CNC simulation. At the end of the project, the new designs were prototyped and the best model machined in a CNC machining center. We have established positive and negative aspects of the PLM experience and students' impressions.

Keywords: collaborative engineering; product lifecycle management; engineering education; computer aided tools; integrated design and manufacturing

INTRODUCTION

IN THE NEW SCENARIO of global competitiveness, companies are forced to outsource and distribute product manufacturing in order to minimize costs and delivery times. Nowadays, engineering education must encourage students to work according to this trend by taking advantage of the recent developments of groupware or Computer Support Collaborative Work (CSCW) technologies. Among these and similar technologies, Product Lifecycle Management (PLM) systems provide several functionalities which allow students to learn how they can interact in a distributed environment for collaboration during product design and development.

Product Lifecycle Management tools are used for the storage, organization and sharing of product-related data and for coordination of the activities of a distributed team in the deployment of all products' lifecycle processes such as project and portfolio management, product design, manufacturing planning and process design, supply production, client service, recycling and all related activities [1].

The most immediate forerunners of PLM systems are Product Data Management (PDM) tools, which were designed to be used as engineering databases, storing information such as Computer Aided Design (CAD) models and drawings, Computer Aided Engineering (CAE) analysis, Computer Aided Manufacturing (CAM) processes and many other digital documents.

Nowadays, PLM systems have added to existing PDM tools new applications which offer different capabilities in order to manage a product's lifecycle activities [2]. Generally these applications are:

- Product Data Vault (objects as CAD models, analysis, digital manufacturing, and drawings).
- Product Data and Structure Management.
- Document Storage Management.
- Data Sharing and Exchange.
- Visualization and Notification Services.
- Lifecycle Management.
- Project Management.
- Workflow Management.

Therefore, companies have dedicated great efforts in implementing these new systems in order to improve their processes. However, there is a gap in the engineering education curricula when it comes to teaching graduate students about PLM concepts, and many of them require additional training when working in industry to acquire abilities that should be partly taught in graduate courses.

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Below we analyze the educational efforts conducted in the past in order to educate future engineers in this field. Ye et al. remark the need to define a CAD curriculum in engineering [3]. A brief review of CAX techniques and the educational approaches to teach them in graduate courses are reported. We also present a practical experience conducted in a Computer Integrated Manufacturing (CIM) course for graduate students, where a collaborative product development project is carried out. Through the project experience, the students acquired abilities related to design and manufacturing in a collaborative environment, using CAD/CAE/CAM and PLM software tools. The project let the students learn by practicing through activities such as 3D design, drawings, plastic injection analysis, cutting-tool and fixture selection, cutting parameter selection, and CNC simulation.

ENGINEERING EDUCATION WITH COMPUTER AIDED TOOLS

Nowadays, a product development process can run with computer aided applications. According to the stage of the product development, different CAx tools are used by engineers or specialists (Fig. 1).

These tools cover many technologies such as Computer Aided Design (CAD), Computer Aided Engineering/Simulation (CAE), Computer Aided Process Planning (CAPP), Computer Aided Manufacturing (CAM) or Computer Aided Testing (CAT). Besides, they must be integrated during the process flow with other tools more dedicated to planning activities such as Clients Relationship Management (CRM) tools, Supplier Requirements Management (SRM) tools or Enterprise Resource Management tools (ERP). With the growing integration of these CAx tools the data and information management becomes increasingly important. Nowadays, the complex network of CAx-based systems and the heterogeneous data cannot be handled without PDM tools. PDM tools are regarded as the backbone of modern product design and development, and are now extended to support the whole product lifecycle which leads to the concept of Product Lifecycle Management.

However, in engineering education many of these CAx tools are taught separately, and there is no integrated vision on real product process development. For example, it is common to find courses to teach CAE fundamentals, others to teach CAD fundamentals, and so on. In general, the lack of an integrated vision in the basic engineering curriculum overlooks the necessity of teaching valuable skills in the following areas:

- Team management and workgroup management in cross-functional distributed teams.
- Identification and resolution of manufacturing problems due to inefficient designs.
- Efficient collaboration between designers and manufacturers.
- Lifecycle management and workflow management for product development.

Some efforts have been conducted and reported in the literature in order to overcome these curriculum limitations. For example, Lee et al. developed a learning collaborative environment for designing and prototyping a working toy using CAD and web-based learning software [4]. Asperl proposed some didactic principles for teaching CAD [5]. Although the student had a global vision from the 3D design to the final product, the student only worked with a CAD system, and no attention was paid to CAM/CAE and PLM systems. Dank-

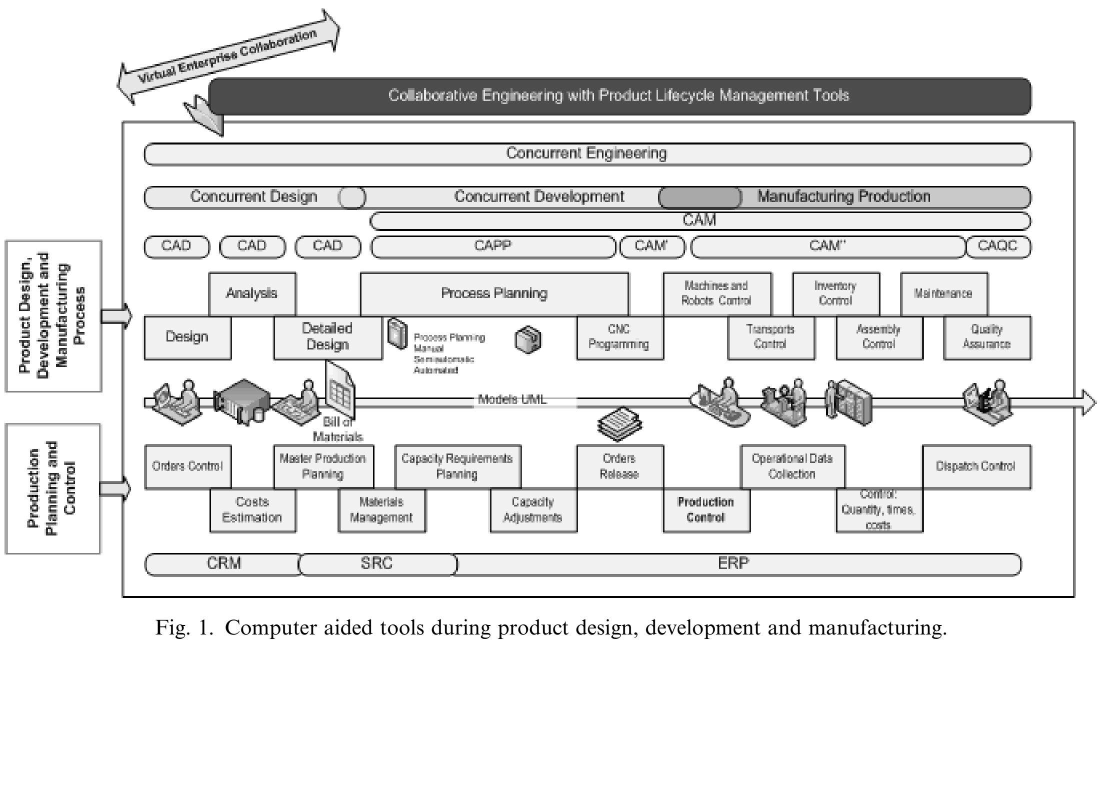


Fig. 1. Computer aided tools during product design, development and manufacturing.

wort et al. analyzed the phases of product design (creative, conceptual, and engineering) and suggested some best practices for CAx education considering the relevance of Information Technology knowledge [6]. He remarked the importance of practical experiences in PDM/PLM applications which are often not taught due to limits in curricula. Tomovic and Wisma described a PLM experience in a senior design course where the students work in all aspects of product design cycle, from concept design, product optimization, to manufacturability. In spite of the interesting experience reported it is not clear how PLM software was used; it seems to have beeen only used for file storage and sharing [7, 8]. Buchal developed a training strategy for working with a PDM tool and managing CAD shared data. He presented a case study in which the students designed an airplane assisted by commercial PDM and CAD software [9]. Warminski et al. focused on developing an integrated project from design to manufacturing including rapid prototyping [10]. Guerra-Zubiaga et al. presented a Problem Oriented Learning (POL) methodology for applying Product Lifecycle Management, in a case study related with the automotive industry. They used digital manufacturing software for designing and simulating, in a collaborative way, a real manufacturing assembly plant with robotic cells [11]. Dennis and Fulton described a real distributed collaborative product development experience conducted by mechanical engineering students from Georgia Tech and the University of Maryland College Park [12]. Although this experience was mainly related to design activities, the students also learnt the importance of coordination and collaboration through PLM software. Finally, most academic proposals agree the necessity of developing Integrated Product and Process Design and Developing Projects to readdress the education of engineering students [13, 14].

However, important aspects of PLM were not used, such as workflows or milestones. In general, all project experiences presented in the literature claim that the future of engineering education must involve integrating IT into classroom to foster multidisciplinary distributed collaborative product development [15]. It is also clear that the advantages of learning by "doing" and "experiencing" and the students' interest for these product development experiences are considerable.

It can be deduced from the literature that there are many efforts in an engineer's education involving the new applied information technologies but there is still much work to do. New tools are being developed around internet protocols to enable engineers to work with information and communication technologies. These new environments require not only technical knowledge about different engineering disciplines but also a new way of working and a new culture that must be taught in engineering schools. Working with automated workflows, milestones and other functions is going to be one of the mainstays of integrated product design and development in a real and distributed industrial scenario.

Below, we propose a practical PLM experience for computer integrated manufacturing courses to teach fundamentals of CAD, CAE, CAM and PLM systems in an integrated way. The main idea is to work on a simple product from design to manufacturing using PLM software to coordinate the product development by means of workflows, workgroups, roles, permissions, etc. Through this experience, the students learn by practicing through activities such as 3D design, drawings, plastic injection analysis, cutting-tool and fixture selection, cutting parameter selection and CNC simulation.

COMPUTER INTEGRATED MANUFACTURING COURSE

The Computer Integrated Manufacturing (CIM) course is given in the last semester of a Master of Science degree at Jaume I University (Spain). According to the European Credit Transfer System (ECTS), the course consists of six credits, which are divided into 30 lecture hours, 30 lab hours and 90 hours for project and homework tasks. The average number of students enrolled per year is around 15, which facilitates the workgroup learning methodology adopted.

Competencies to be acquired

According to the new European Higher Education Area (EHEA), each course should define the competencies that will be acquired by the master students. The main competencies developed in the CIM course are listed as follows:

- To know concepts about computer manufacturing integrated systems, including existing proposed models.
- To be able to use computer aided tools such as CAD/CAE/CAM and PLM software.
- To be able to work and taking decisions in workgroups to develop a product concurrently.
- To be able to plan manufacturing processes for part machining and proper cutting parameter selection.
- To know different automated manufacturing systems to improve production systems.

Lecture and lab topics

The lecture topics cover three main areas or parts:

1) New manufacturing paradigms,
2) CAD/CAM/PLM fundamentals,
3) Automated manufacturing systems.

The first part introduces the new manufacturing management trends and the proposed models for manufacturing integration. The second part deals with design and manufacturing computer aided

Table 1. Lecture and labs topics

Week	Lecture Topic	Lab Topic
1	New Generation Manufacturing Systems	Basic Modeling Concepts I (ProEngineer)
2	Integrated Manufacturing and Production Systems	Basic Modeling Concepts II (ProEngineer)
3	Computer Aided Design	PLM Concepts (PDM/Link, ProductView)
4	Computer Aided Engineering	Part Assembly (ProEngineer, PDM/Link)
5	Computer Aided Process Planning	Drawings (ProEngineer, PDM/Link)
6	Computer Aided Manufacturing	Basic Milling concepts (ProEngineer, PDM/Link)
7	Concurrent Engineering	Milling concepts (ProEngineer, PDM/Link)
8	Flexible Manufacturing Elements	Advanced Modeling Concepts (ProEngineer, PDM/Link)
9	Flexible Manufacturing Systems	Advanced Milling concepts (ProEngineer, PDM/Link, Vericut)
10	Control of Flexible Manufacturing Systems	Project Sessions
11	Computer Integrated Quality Systems	Project Sessions
12	Controlling and Planning Shopfloor Level	Project Sessions
13	Seminar	Project Sessions
14	Seminar	Project Sessions
15	Seminar	Project Sessions

concepts in collaborative environments which are complemented with the lab sessions. Finally, the last part shows the benefits of modern manufacturing equipment related to automated manufacturing systems.

The lab sessions which complement the lecture classes are also divided into three parts:

1) Computer Aided Design—CAD,
2) Product Lifecycle Management—PLM,
3) Computer Aided Manufacturing—CAM.

The first part of the lab session is used to teach students CAD software for 3D solid modeling, drawing and assembly. The second part is used to teach the basic concepts of PLM software such as: check in parts, check out parts, update parts, promote parts and add comments on parts for revisions through independent visualization tools for CAD models. The final part of the session is used to teach how to define cutting tools and fixtures for any operation, how to select cutting conditions, how to create numerical control sequences and simulate the cutting operation result.

Resources

To support the individual and workgroup practical sessions, specific resources related to software and physical equipment are required. The faculty owns licensed copies of Pro/ENGINEER 3.0 CAD/CAM tool and PDM/Link 8.0 software developed by PTC using a Java based proprietary Windchill architecture. The PLM software is installed in a powerful server that is accessed by students from classrooms equipped with PCs where a copy of Pro/ENGINEER 3.0 is installed. The access to the server is granted via the VPN (Virtual Private Network) offered by the university to all students. In addition, physical equipment for both prototyping and manufacturing purposes is available in the laboratory of manufacturing processes. The rapid prototyping machine used in the CIM course is a Stratasys 3D printer with paraffin-based polyester material. For machining, the CNC machining center used is a DeckelMaho DMC70V with a wide range of cutting tools for face-milling, end-milling, and drilling operations. Figure 2 shows the available equipment for the CIM course. In that way, the students make

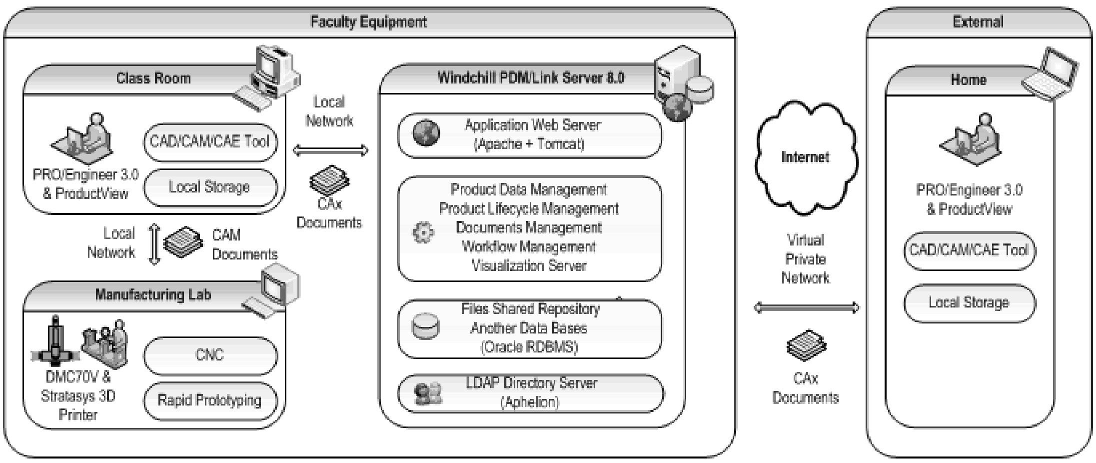


Fig. 2. Available equipment for the CIM course.

contact with equipment they could find in a professional environment.

LEARNING THROUGH COLLABORATIVE PRODUCT DEVELOPMENT

The goal of the project course is to simulate the collaborative product development of a geographically dispersed enterprise. For this purpose, three teams (Team A, B, and C) for both design and manufacturing activities are defined, each of them composed of three members. Each team has two responsibilities: first design a new product model which meets the design specifications and its plastic injection mould, and second, plan the manufacturing process of the required moulds created by another team. For this project experience three new products are designed and manufactured: the new model 1 is designed by Team A and its process planning is developed by Team B. The new model 2 is designed by Team B and Team C produces the process planning. The new model 3 is designed by Team C whereas the process planning is developed by Team A. In that way, each team plays all possible roles during product development.

Project context

The collaborative product development experience is based on a hypothetical enterprise with Design and Manufacturing departments dispersed geographically. The enterprise manufactures toy cars, composed of plastic components which can easily be mounted and exchanged with new components. Due to marketing and management interests, three new toy cars have to be released which should be more customized than the previous model. The new designs are then requested to the design office who works in collaboration with the manufacturing office to reduce the lead time and costs though product process development. A visual scheme of this hypothetical enterprise with the old design model is shown in Fig. 3.

Product life-cycle management tool functionalities

The main core of this engineering educational course is the use of a commercial PLM tool. Such tools have similar architectures and functionalities. The basic architecture of PLM is in four main generic functions that cover (Fig. 4):

- Data Management. Brings support for the identification, structuring, classification, modeling, recovery, dissemination, visualization, and storage of product and process data.
- Workflow Management. Brings support for modeling, structuring, planning, operating and controlling formal or semi-formal processes such as engineering release processes, review processes, change processes, or notification processes.

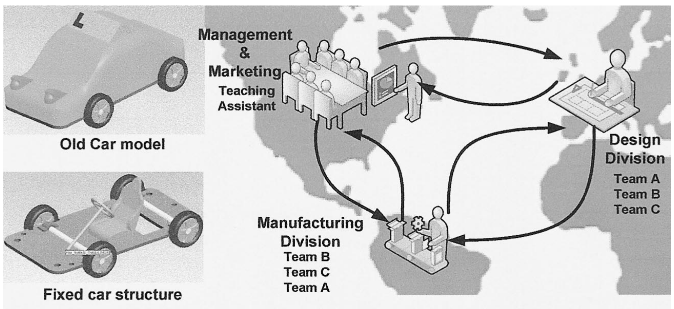


Fig. 3. Hypothetical enterprise simulated during product development experience.

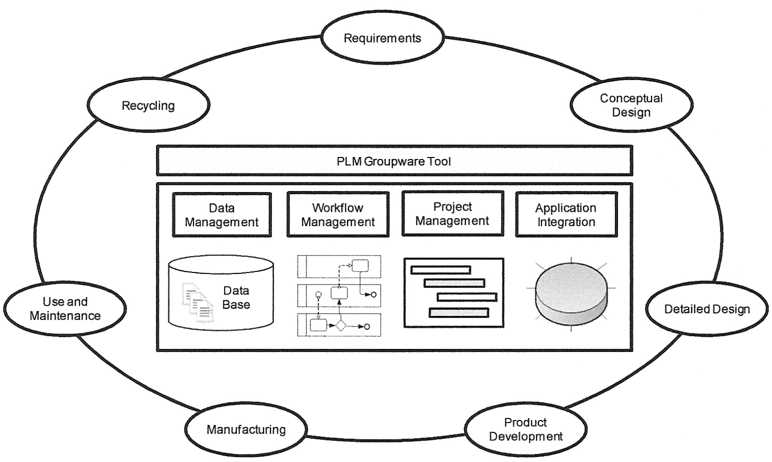


Fig. 4. Basic components of product lifecycle management tools.

Table 2. Activities conducted in collaborative product development process

Activities	Tasks	Resources	Requirements
Design	Design a new toy car model more Sportive subjected to old car model restrictions. Files to generate: parts, drawings for each part, assembly file, assembly drawing with BOM	Pro/ENGINEER PDM/Link ProjectLink ProductView	Design specifications (old car model). Design considerations for manufacturing.
Analysis	Analysis of plastic injection. Creation of moulds to manufacture the car parts modeled. Files to generate: Plastic analysis file and mould parts.	Pro/ENGINEER PDM/Link Plastic Advisor tool	Mold Design considerations Design for Plastic Injection
Process Planning	Machine-tool, Fixture, and cutting-tool selection. Cutting-tool parameters selection to manufacture one of the moulds previously generated. Files to generate: Manufacturing files where CNC sequences with cutting tool parameters are defined.	Vericut Pro/ENGINEER PDM/Link ProjectLink ProductView	Recommended cutting tool parameter ranges. Cutting-Tools capabilities
Manufacturing	Demonstration phase, where the new car models are prototyped. The best model is selected to manufacture its mould.	Rapid Prototyping Machine (Stratasys) CNC Machining Center (DMC70V)	Machine-Tool limitations

- Project Management. Makes it possible to plan, manage, monitor and control the entire project development process, from initial idea to completion, allowing project managers to control project structures, schedules, costs, and resources.
- Application Integration. Brings support for defining and managing interfaces between PLM and different authoring applications such as CAD, CAM, CAE, and integrated enterprise software such as ERP (Enterprise Resource Planning) systems.

Each one of these functions has been implemented in the PLM tool used in this course (Windchill) through the following:

- Windchill PDMLink®: This functionality has all the Data Management utilities, for example, product data vault, structure and document management, data sharing and visualization. This is the core functionality of the system and it offers a secure, controlled storage for all the data and meta-data. It also includes an application that can offers collaboration through design libraries, Windchill PartsLink™:
- Windchill ProjectLink™. This functionality integrates different utilities for lifecycle management including the Workflow application and the notifications and discussions tool.
- Windchill Workgroup Manager for MCAD. This functionality integrates different and heterogeneous CAx applications (AutoCAD, CATIA v4, CATIA v5, Inventor, SolidWorks y UG-NX).
- Windchill Enterprise Systems Integration (ESI). This functionality has the aim of integrating the PLM, product structure and designs, with ERP tools in a bidirectional.

For this engineering educational course PDMLink and Project Link have been used.

Project activities

The project was divided on four main activities (Table 2). The first activity focuses on learning advanced CAD tools to design a new toy car model which replaces an old car model version provided by the teacher. The specifications are not directly reported, and the students have to extract all specifications from the old car version (clearances, required dimensions, material, etc.). Students have to consider some design considerations for plastic injection components in order to make feasible the manufacture of the new model. As a second project activity, students analyze the plastic injection of their components, and design a single mould to manufacture the plastic component. This activity is assisted by the teacher as some of the concepts required in this part are not directly taught in lab sessions, but only provided in some useful tutorials. In the third project activity students have to work on CAM concepts to elaborate the manufacturing process plan. At this point, students have to select the more appropriate cutting-tools and cutting tools parameters according to recommended cutting tool parameter ranges and machine-tool limitations utilized at the faculty manufacturing laboratory. As a final activity, the students manufacture their designs by rapid prototyping, and the best body car design is selected to machine its mould.

Product life-cycle definition

A product lifecycle with stages is defined to manage the different phases of the product components through development. For the presented project, all product components have the same life-cycle with four possible phases:

1) Design,
2) Reviewed,
3) Process Planning,
4) Manufacturing.

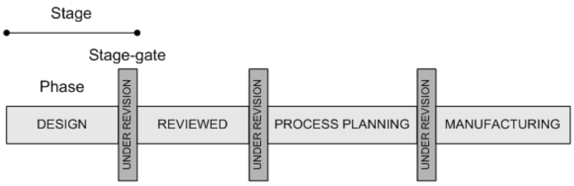


Fig. 5. Product lifecycle defined with four possible phases.

To promote from one phase to another, a phase promotion request (stage-gate) is required and the new phase is not set until the design or manufacturing manager reviews the component and accepts or rejects the request. The "Design" phase is defined when the component is being designed or re-designed. The "Reviewed" phase is reached when the component design has been approved by the design manager. The "Process Planning" phase is defined when the manufacturing files are created to start the process planning tasks. Finally, when the process planning is approved, the "Manufacturing" phase is reached. Figure 5 shows the lifecycle created in the project.

Roles definition

In order to create a real product development environment, four main roles are defined:

1) Designers. Members of the design department who have to design a new car model. This role is played by Teams A, B, and C.
2) Process Planners. Members of the manufacturing department who have to select machine tools, fixtures and cutting tools to manufacture the moulds created in a new model design. These planners are also in charge of cutting-tool parameters selection and numerical control sequences generation. This role is played by Teams B, C and A.
3) Design Manager. Someone in charge of the design department who is responsible for supervising and validating the new design car model. This role is played by the teaching assistant.
4) Manufacturing Manager. A member who is in charge of the manufacturing department responsible for supervising and validating numerical control sequences and the cutting-tool selection to manufacture the moulds created for the new design car model. This role is played by the teaching assistant.

Workflows definition

With the help of the PLM system, a workflow is defined to manage the information flow and the activities of each role during the collaborative product development according to the product development phases which are defined by the product lifecycle. The workflow created in the project is shown in Fig. 5; it relies on the collaboration of the roles defined previously. When a new car component is created, its initial phase is "Design" according to the lifecycle defined above. During this phase, the designers of this new car component are in charge of the new design. When the design is finished, the designers request a promotion to the next phase called "Reviewed". At this time, the new car design is ready to be evaluated by the design manager, who is being asked to approve it in order to start collaboration with manufacturing department.

The design manager checks the component files (3D models, injection analysis files, and drawing dimensions), and approves or rejects the design. The design manager decides, and makes the necessary comments and annotations to improve the design. These annotations are done through a CAD visualization tool (ProductView), so CAD software is not required in the revision process. In case the promotion is rejected, the designers

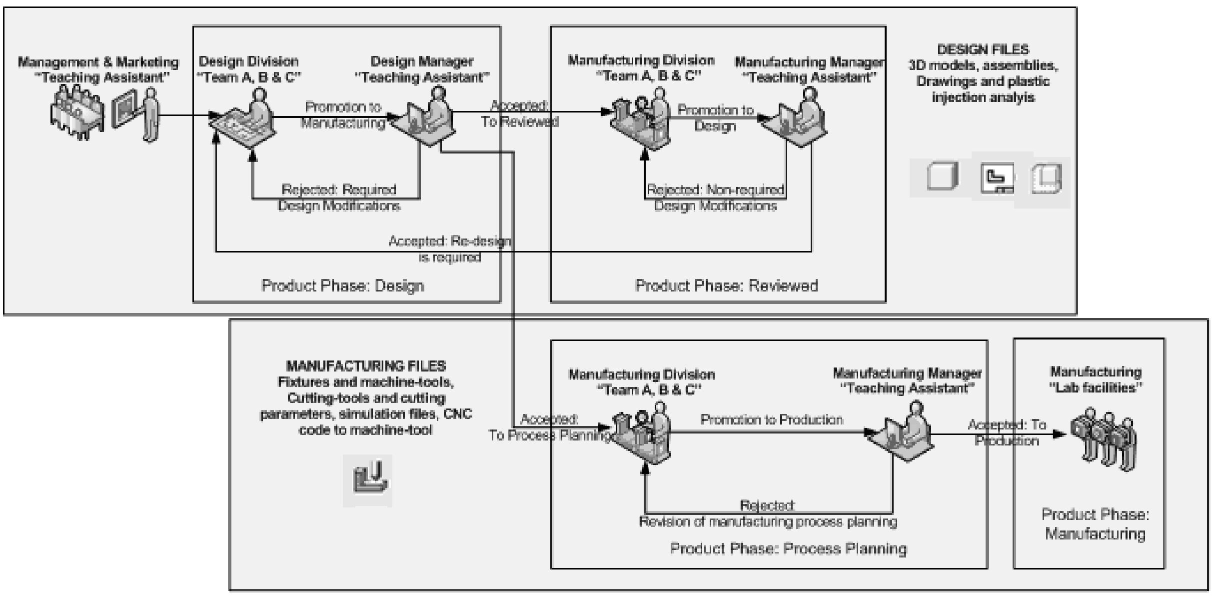


Fig. 6. Workflow defined in collaborative product development process.

Table 3. Permissions set up for the Design phase in the PLM

Product Phase: "Design"				
Type of Permission	**Roles**			
	Designer	**Design Manager**	**Process Planner**	**Manufacturer Manager**
Read Only	–	–	–	–
Modify	√	–	–	–
Create	√	–	–	–
Total Control	–	√	–	–
None	–	–	√	√

Table 4. Permissions set up for the Reviewed phase in the PLM

Product Phase: "Reviewed"				
Type of Permission	**Roles**			
	Designer	**Design Manager**	**Process Planner**	**Manufacturer Manager**
Read Only	√	–	√	√
Modify	–	–	–	–
Create	–	–	–	–
Total Control	–	√	–	–
None	–	–	–	–

Table 5. Permissions set up for the Process Planning phase in the PLM

Product Phase: "Process Planning"				
Type of Permission	**Roles**			
	Designer	**Design Manager**	**Process Planner**	**Manufacturer Manager**
Read Only	√	√	–	–
Modify	–	–	√	–
Create	–	–	√	–
Total Control	–	–	–	√
None	–	–	–	–

Table 6. Permissions set up for the Manufacturing phase in the PLM

Product Phase: "Manufacturing"				
Type of Permission	**Roles**			
	Designer	**Design Manager**	**Process Planner**	**Manufacturer Manager**
Read Only	√	√	√	√
Modify	–	–	–	–
Create	–	–	–	–
Total Control	–	–	–	–
None	–	–	–	–

receive an e-mail notification to modify their design according to the annotations and comments provided. Otherwise, the promotion is approved and the component is now set up to the "Reviewed" phase.

At this stage, the process planners have a read-only access to the new design components; new manufacturing files for process planning are created by the design manager with the product phase "Process planning". These manufacturing files are only accessed by process planners, who have to add the information related to the proper machine-tool, fixture, cutting tools, and correct numerical control sequences. During the process planning, if design modifications are required, the design components with the "Reviewed" phase are requested to be promoted to the product phase "Design".

Design changes are provided by comments and annotations through ProductView. If a re-design is required, the promotion is approved, and the components are set up again to the "Design"

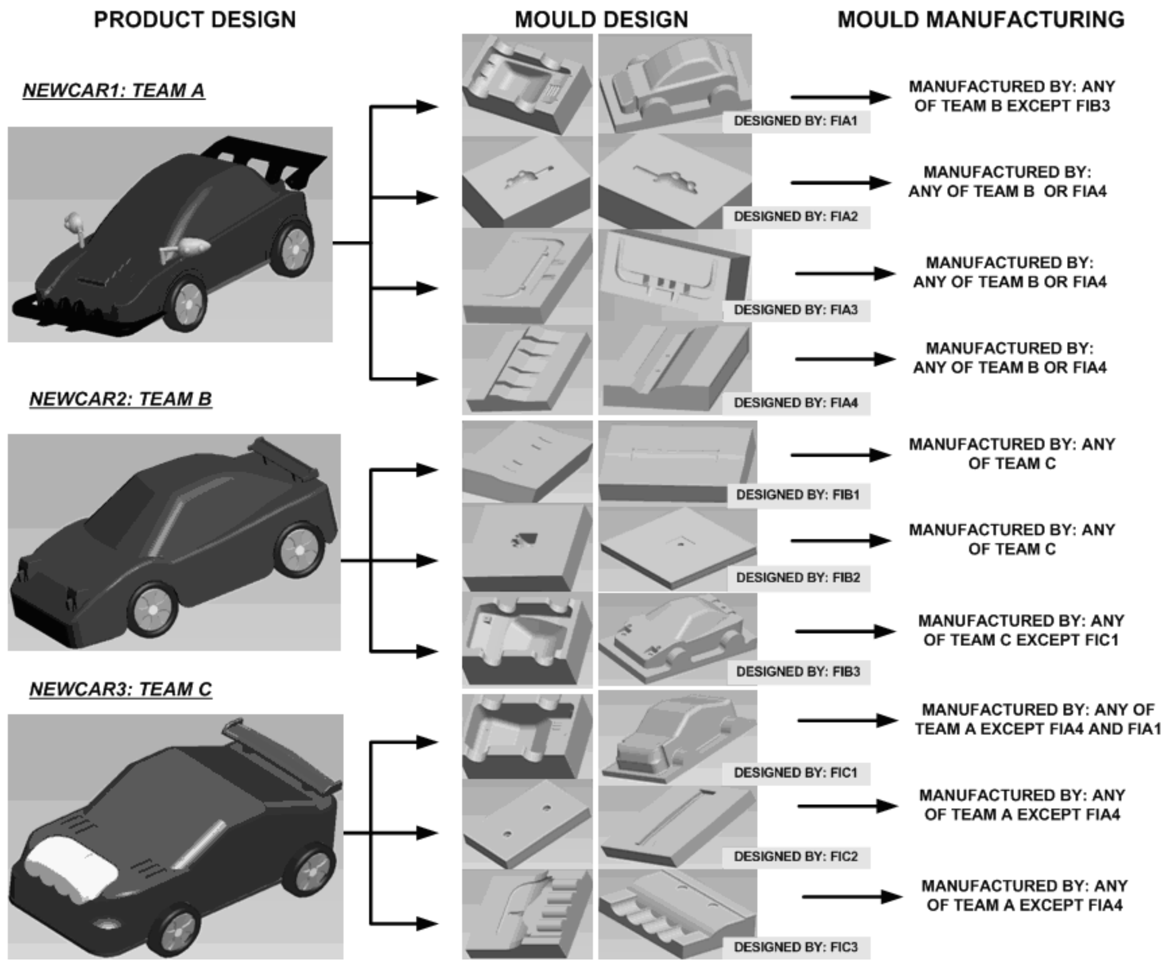


Fig. 7. Products elaborated by students during the project.

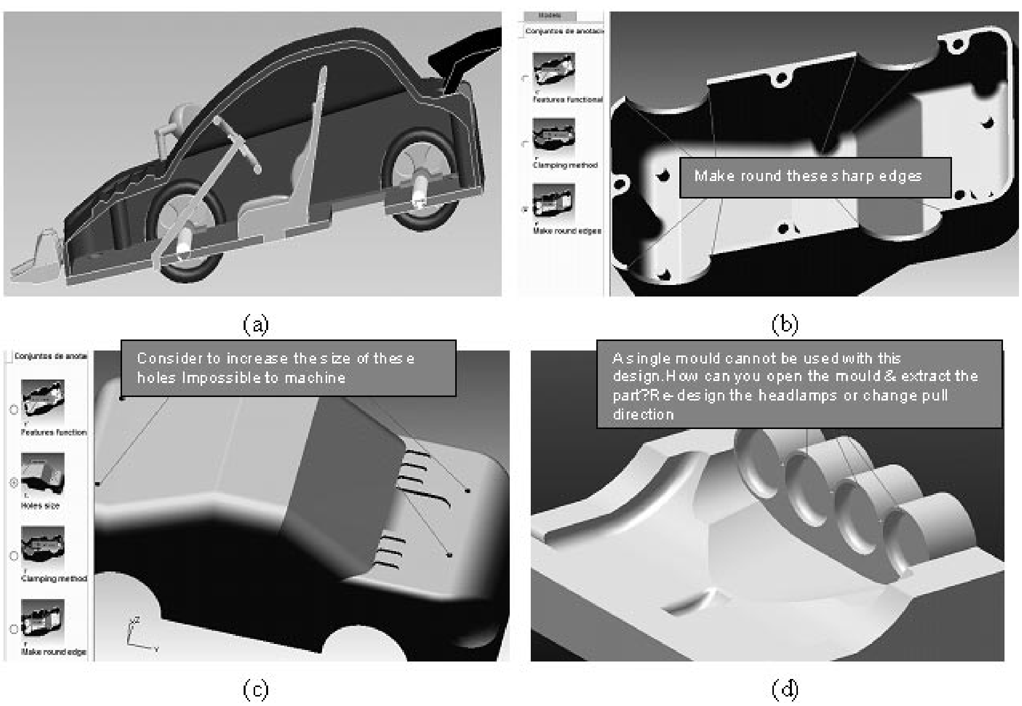


Fig. 8. Examples of engineering change orders, demanded by the design manager, during the first promotion. (a) Body car collides with the steering wheel. (b) Body car edges have to be round to manufacture the body car mould. (c) Holes to assembly different components require a minimum size. (d) A single mould cannot be applied for manufacturing this part.

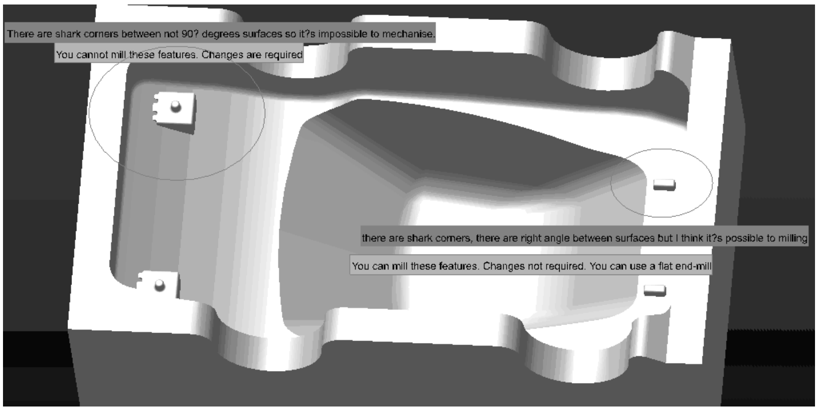


Fig. 9. Example of design changes demanded by a student in the process planner role. Sharp edges are reported although only one of them requires a design modification. Red comments are reported by the student whereas green comments are reported by manufacturing manager.

phase when designers can proceed. If a re-design is not required, the promotion is rejected and the process planner has to modify the process planning with comments or advice provided by the manufacturing manager. When the manufacturing process planning is finished, the process planner asks for a new promotion to change the manufacturing component phase from ''Process planning'' to ''Manufacturing''. If the process planning is correct, the manufacturing manager approves the promotion, and the collaborative product development is finished. Otherwise, the promotion is rejected and comments and annotations are provided to improve the process planning.

Matching roles and permissions for each phase

The permissions for each role through the collaborative product development are defined according to each product phase. These permissions are set up in the PLM software as it is shown in Tables 3–6.

EDUCATIONAL PLM PROJECT RESULTS

After the collaborative product development process, three final toy car models were developed by the students with moulds, drawings, plastic injection analysis and process planning files as shown in Fig. 7.

During the collaborative product development process, three kind of promotion request were tracked as explained above. The promotions were used by the teaching assistant to track the project evolution during the course and to assist in design and process planning problems. The first promotion showed common design mistakes detected by the teacher acting as the design manager, such as assembly problems and part features which cannot be manufactured in a conventional machining center. Comments provided by the teacher were reported through ProductView to improve the design. Some of these comments are shown in Fig. 8.

The second promotion showed common design mistakes detected by the process planner. These mistakes are reported through ProductView to be verified by the teacher acting as the manufacturing manager. The process planner's request is provided by comments in red color whereas the manufacturing manager's comments about requested changes are in green color. Typical design changes reported in this promotion were sharp edges, thin walls, and inefficient designs (non-standard dimensions, different dimensions for similar features, etc.). Figure 9 presents an example during the process planning of the car model number 2.

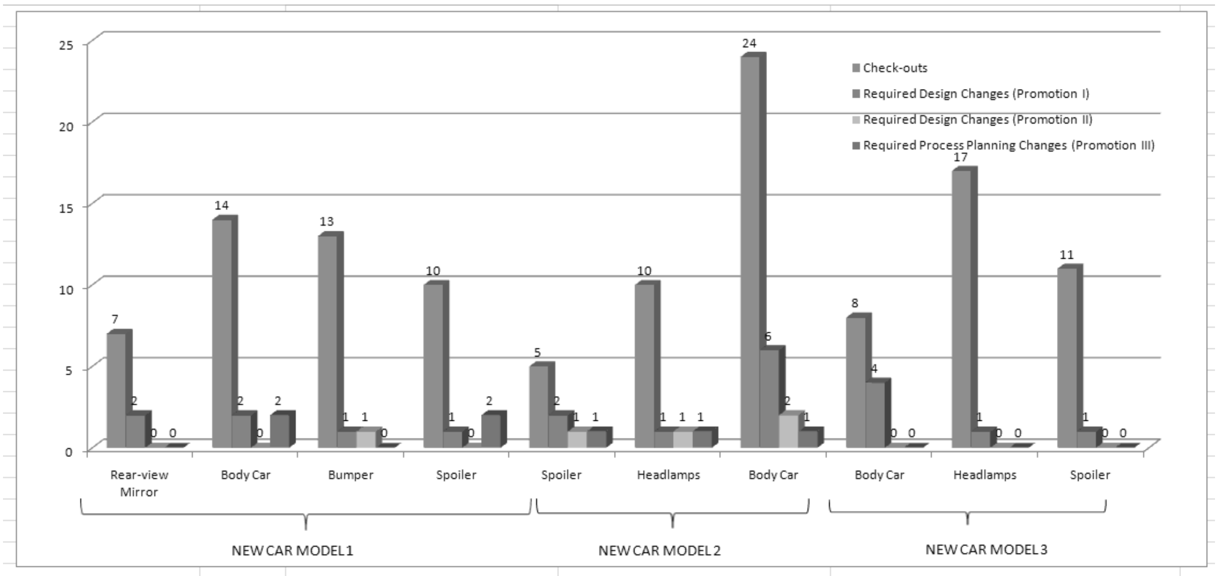
Finally, the third promotion showed common process planning mistakes detected by the teacher acting as the manufacturing manager, when the process planner requests that the promotion goes to production. Typical mistakes encountered here were inefficient cutting-tool selection, incorrect cutting parameters, cutting-tool collisions, excessive material removal rates, etc. Figure 10a presents an example where the manufacturing manager explains with comments how to improve process planning.

The total number of promotion requests for each car component was recorded in order to evaluate the workload of each team during the project. In addition, the check-outs of each component were monitored as a good indicator of the time dedicated per student. Figure 10b presents a summary of this tracking process in two forms.

As shown in Fig. 10, the body of car model 2 was the component which required more time dedication for both design and process planning due to design complexity. Otherwise, the body of car model 3 required less time dedication although a large number of design changes were requested by the design manager. The process planning of all components from new car model 3 were conducted by the process planners without any change demanded by the manufacturing manager. The other car models required several process planning changes. In general, all car components had an adequate time dedication except for the body of car 2.

Nombre de la actividad	Encargado	Rol	Voto	Status	Comentarios
Approve Promotion Request	FID1	Aprobador	Reject	✓	Although the machining files are correct, some modifications are required: 1- The first rough operation should be with a bigger tool to minimise the cutting time. 2.- The finish operation is not done with a ball mill, so the surface finish is not adequate. Try to change to a mill with a code FR-CO-.... Promote again with these changes.

(a)



(b)

Fig. 10. Project activities tracking (a) with comments (b) with graph.

Fig. 11. Rapid prototypes of new car models.

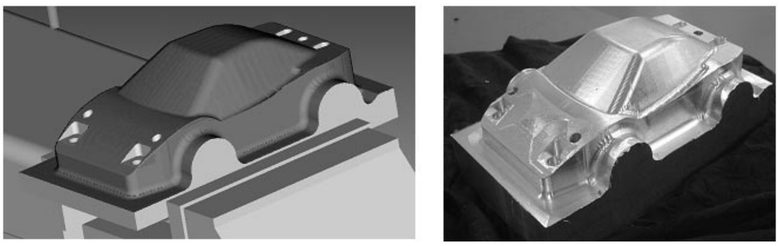


Fig. 12. Machining process simulation using Vericut and final machined mould (body car of new car 2).

After approving the new car models, the product development was finished. Finally, the new car models were manufactured by rapid prototyping and assembled. Figure 11 shows the car models prototyped. The body of car model 2 was selected to show the machining process of one of the moulds designed by the students. Figure 12 shows the machining process and one part of the body car mould machined at the faculty facilities.

LESSONS LEARNED AND FUTURE CHALLENGES

At the end of the project, a feedback from the students was provided with some interesting comments (see Fig. 13). The positive and negative aspects of the experience and the feedback comments can be listed as follows:

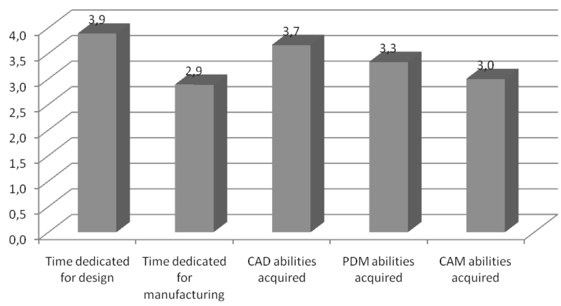


Fig. 13. Feedback poll results to analyze student opinion. Scales: 1. Very little/low, 3. Adequate, 5. Too much/very high

- Positive Aspects:
  - Students find the overall project experience exciting.
  - Unlike other course activities conducted in previous years, this project tries to force the student to work in a more realistic scenario which is fundamental for graduate students.
  - The common lectures about design and manufacturing problems are reflected in this project
  - The good level of CAD/CAM/PLM skills that the students develop through the semester demonstrates the effectiveness of the project, as was also indicated by the students in their feedback.
  - Comments reported by the promotion request (approvals/rejections) were considered highly useful for students and teachers, because it facilitates the identification and resolution of committed mistakes.
- Negative Aspects:
  - Because of time limitations, some important topics through the project could not be taught as well as should be. For example, some considerations for cutting-tool parameters selection such as machine-tool power restrictions or tool-path strategies were omitted.
  - Some important considerations on plastic injection analysis were omitted, and the students only learnt a general idea about the process, which could lead a misunderstanding about the complex process of plastic injection.
  - Students' work is not balanced, and some had to work harder than others according to their design decisions which in some cases increase the component complexity.

Students' opinion of the PLM tool can be summarized in two main estimations. On the one hand, it is hard to manage because it is not intuitive (although it is based on web interfaces developed on Java) and the learning curve is difficult for beginners. On the other hand, the tool enables collaboration and cooperation between different product design and development activities and it put together all the engineering capabilities acquired during the student's formation.

After the project, some recommendations to improve the CIM senior course were outlined by the teaching assistants. First, the product to be designed should be less complex with more design restrictions in order to reduce time spent on design tasks. As a secondary consideration, it was recommended that design activities should be reduced in favor of time spent on advanced CAM concepts, in order to find a trade-off between design and manufacturing tasks. Finally, the senior CIM course could be extended to include students from other universities or master courses to reflect more accurately the problems presented in geographically distributed scenarios.

CONCLUSIONS

Despite many efforts from the industry to apply PLM functionalities, there is still a dearth of graduate engineering curriculums that teach and practice concepts related to collaborative product development. Previous research work corroborates that educational efforts are required to give future engineers skills that could be applied in this area. Our work tries to overcome these limitations through a product development experience in a senior Computer Integrated Manufacturing (CIM) course where students were introduced to modern CAD/CAE/CAM and PLM software tools.

The project let the students learn by practicing through activities such as 3D design, drawings, plastic injection analysis, cutting-tool and fixture selection, cutting parameter selection, and CNC simulation in a collaborative way. By the end of the project, the students had become familiar with equipment such as rapid prototyping and CNC machining center, which were used for manufacturing some of their models. The project experience was considered by the students to be exciting and useful; their feedback will be used to improve the course in future.

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