Use of an Open-Source PLM solution to improve teamwork performance in product design courses

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Abstract

As Product Lifecycle Management (PLM) strategies are getting more and more common worldwide, developing countries have the increasing industrial need of engineers trained on these technologies. This is motivating academic institutions to tackle this issue by integrating PLM in their curriculums. This paper describes a pilot implementation of a PLM strategy in a Product Design Project Course at EAFIT University. The PLM strategy is used to support the development of the design process and teamwork performed by students. During two consecutive academic periods the course was analyzed, a PLM strategy was prepared and executed, and monitoring was carried out to obtain comparative data on the success of the implementation. An evaluation was performed on the role this implementations can have in improving drawbacks that usually arise during the development of collaborative design projects amongst students. Open-Source PLM Software was employed to facilitate future application of these tools by the students themselves in their future employments.

1 Introduction

Product Lifecycle Management (PLM) is nowadays a common industrial philosophy to manage product information and collaborative design. It started on aeronautics and automotive industries but it is spreading around the world to other industries and countries. This is why developing countries have been faced with adopting this way of working. Universities have started to prepare engineers with a strong basis on collaborative work combined with information technologies. In Colombia, PLM strategy is barely known in the industry, but it is a reality that will arrive in the near future. PLM systems are then a challenging approach that has to be mastered by today’s world class engineers. According to Bordogna et al. [1] within university communities, in particular, we must create an intellectual environment where students can develop an awareness of the impact of emerging technologies, an appreciation of engineering as an integral process of societal change, and an acceptance of responsibility for civilization’s progress.

EAFIT University fosters the idea of project-based learning and teamwork. Yuliang Li et al. [2] claim that intelligent collaborative product design is needed in the product design process. To an increasing degree, design is being recognized and taught as a team process with multiple socio-technological dimensions [3]. Both cornerstone and capstone project-based courses are seen as opportunities to improve students’ ability to work in teams, as well as their communication skills [4]. Bucciarelli [5] defined “design as a social process” in which teams define and negotiate decisions. Minneman [6] also argued that those views shift the focus of group design support onto communication systems and that “design education should be refocused on teaching designers to better function in group situations.”

Teamwork is an essential part of the product design process and its proper development is critical for a project’s success. In a survey performed to 151 Product Design Engineering students at EAFIT, most of them (68%) answered they have a positive attitude towards teamwork and identify it as important for their learning and professional development [7]. Collaboration, however, is not as natural and automatic as one might think, according to Santoro et al. [8] a collaborative attitude is a cultural matter. Torres and Tomovic [9] mention that the lack of formal preparation and the involvement of many stakeholders in decision-making arise numerous problems at every stage of the collaborative engineering design process. In EAFIT University’s experience, many difficulties have been identified in the collaborative design process that the students perform, amongst these; in the management of information, task planning and control, workload distribution amongst team members, compliance, workload distribution throughout the course duration, etc.

According to Santoro et al. [8] the key aspect behind effective collaboration is the process. Process planning demands collaborative work, information sharing, and the exchange of ideas among multiple parties in different locations. Of these, perhaps sharing and managing information is the most recurrent problem that arises during the development of collaborative projects. As Finger et al. [10] points out, without a central repository for both physical and electronic artefacts, the necessary co-construction of knowledge is lost during the project cycle. Team members lose the opportunity to build on each other’s work and, more importantly, to learn from one another.
These are some of the issues that PLM, as a strategy and IT innovation, was designed to tackle in the industry. It helps to have control of a product’s information during its whole lifecycle. Its use helps to manage a project in an organized manner and has access to all the information and resources necessary to execute it. According to Cummings [11], the implementation of a new Product Lifecycle Management (PLM) system results in cultural changes that affect how people involved in the system locate and manage their data. EAFIT University aimed to translate PLM into its educative environment and evaluate the student’s appropriation of the new work strategy as well as its results and impact on the development of their project and overall teamwork performance.

Previous uses of PLM in education have been documented. Humann et al. [12] describe the application of PLM to Micro-Electro-Mechanical Systems (MEMS) devices in education. Vila, C., et al. [13] describe a collaborative product development experience in a senior Integrated manufacturing course using Product Lifecycle Management tools. The same author compares, in a different paper, two different approaches for Project-Based Collaborative Engineering Design and Manufacturing engineering education with PLM Tools [14]. Vaidyanathan, V. et al. [15] discuss the introduction of Product Lifecycle Management (PLM) concepts in a graduate instrumentation course. Likewise, a great number of PLM courses are taught worldwide and some of these have been documented in scientific literature. Torres and Tomovic [9] proposed in 2007 a possible curriculum plan for a PLM course, stressing the necessity of teaching PLM to students and employees. Wittenborn, D. et al. [17], Moon, Y.B. [18], Kakehi, M et al. [19], amongst others, have also provided literature about PLM courses.

While PLM education in many developed countries focuses on generating a PLM literate workforce to adapt to the new technological advances already found in the industry, EAFIT seeks to become an active promoter of these technologies that are hardly known in Colombia, as well as many other developing countries. There is currently not much demand from the industry in Colombia for employees that are literate in PLM, but the focus of the University is to graduate students that have the knowledge and the tools to propose these strategies themselves once they graduate. To facilitate this permeation of PLM in the local industry, costs of implementation need to be reduced. In this scenario, Open-Source PLM software has enormous strategic benefits.

Additionally, scarce literature has been found on the benefits that an implementation of PLM brings for the development and outcome of University projects themselves. Aside from the pedagogic value of University projects, the outcome is also important in the sense that the product designed has to reach a quality that could potentially, and in fact occasionally does; compete in the real market. The process and methods employed are also evaluated with these criteria. One of the reasons for this is that several of EAFIT’s projects, included the one analyzed on this paper, are industry sponsored and the companies involved always expect real solutions to be generated and not exclusively pedagogic exercises.

This paper therefore discusses the direct impact that the implementation of PLM tools had on a specific course from the Product Design Engineering bachelor program. The course is offered after 8th semester and is called “Project-8” (abbreviated as “P8”). It makes part of a series of project courses taught during the first eight semesters of the program where students have to develop a design project under a predefined topic (for P8 it is “Electric Mobility”). The course’s objective is to apply the knowledge acquired by the students during their formation in the design and development of a product for a company during the whole semester duration in teams of six students. The design process goes from the “need analysis” to a “functional prototype construction”. One team was followed on the period of P8 prior to the implementation of PLM (2009-2) and two pilot teams were chosen for the pilot Implementation in the following period (2010-1)2. The results of these three teams are compared to achieve quantitative data. The implementation is evaluated according to this data analysis, observations and student feedback.

2 Preparation prior to implement PLM

Before implementing any new academic strategy, an observation phase has to be performed in order to determine the actual state of the course as well as to identify and gather relevant details to be measured. Consequently, the first step towards implementing PLM in Project-8 was studying the design process followed by students. During one academic period the course and its documentation was studied. As mentioned earlier, one particular team of six students was chosen for a close study of their process and methods in order to make a comparison after adopting PLM.

Students are handed at the beginning of the course a guide booklet created by teachers and faculty members with the basic guidelines of the course. The booklet (called project-guide) includes the methodology, grading methods, formats and a basic working plan with deliverables and their corresponding due dates. Under a BPM (Business Process Modelling) approach, all of this information was synthesized in an “AS-IS” process model that was complemented by the use of direct information provided by the students, observation and surveys made to students and teachers. Some of the main issues discovered in this model were:

- Faculty members have identified a lack of process planning in the students. Project deliverables often evidence that results are reached without having followed a previous well planned procedure;
- Workloads amongst team members are not equal and many times teachers are unable to trace this;
- Roles are helpful for distribution of work activities, but the interactions between them must be planned carefully;
- On most cases, physical team meetings are hard to plan and carry out and many times they are unproductive and inefficient;
- Many students are unaware of the sequential nature of some design processes and don’t realize that delays or faults in certain tasks have direct implications in subsequent tasks;
- Project-8 guide booklet is too generic and students do not identify tasks and activities rather than generic stages asked in the booklet;

1 Second semester of the academic year 2009, starting on July and ending on November.
2 First semester of the academic year 2010, starting on January and ending on June.
- Relationships between tasks, information (used and generated), tools and human resources is not correctly defined.

This information was used, together with teachers’ recommendations and the literature review, to generate a new proposal, or “TO-BE” process model, to be implemented in the course to improve PLM benefits. This process was fully documented and modelled using ARIS\(^1\) Event-driven Process Chain (EPC) notation for Business Process Modelling (BPM). It includes all the activities\(^2\) done in the process and for each function a set of tools, events, deliverables and assignees are established. Fig. 1 shows a part of the methodology modelled in ARIS Express software, representing the “Conceptualization Phase” of the design process. All this process documentation is crucial for any PLM implementation and it sets the basis for effective and organized collaboration.

One of the main dilemmas in process planning is the level of detail that the process plan should reach. How in depth the project is defined depends on the project manager. The more detailed the project plan is, the more control he/she has over it, but also the more restrictive it might become for the project executers. In the case of P8, these decisions were taken by the course’s teachers according to the educational purpose the course has. The teachers clearly wanted to gain more control and supervision of the project’s process and development but still leave enough freedom for students to program their project themselves and learn to plan ahead. Providing students with a very detailed project plan at the beginning of the course could avoid learning project planning by having everything already mapped out for them. As Bordogna et al.\(^3\) state, the student should be a willing—preferably an eager—participant in the process of learning and should be a satisfied customer of the process. On the other hand, giving them a very general project plan, like the AS-IS process model, had already proven to be unsuccessful to track project progress and teamwork.

A compromise was reached by generating a plan that had outlined the main activities within each phase of the design process, but left the specific tasks within each of these activities to be planned out by students. Four main phases were established for the design process:

- Design Requirements
- Conceptualization
- Detailed Design
- Product Launch

The main activities that made part of each phase are also specified in this methodology, which was developed in parallel to this implementation project and is currently still under work.

3 Configuration of the PLM Strategy

Product Lifecycle Management is much more than software; it’s a concept, a strategy, a system, a philosophy. Despite this broad understanding of PLM, its successful implementation is subject to proper configuration and implementation with a software tool, through which the whole concept takes shape and actually comes in action.

There are many companies that supply software to support the PLM process. The largest commercial vendors are Dassault Systèmes\(^4\), Siemens\(^5\), PTC\(^6\), Agile\(^7\) and SofTech\(^8\). These companies provide the most complete software packages, but are considered expensive for emerging markets or Small and Medium Enterprises. There is one company that offers an open source PLM software solution, called Aras Corp\(^9\). The fact that Aras Innovator\(^10\) is Open-Source, presented a huge advantage to choose it as the software to be implemented on Project-8 course. It has possibly a greater expansion potential in the Colombian market, at least in the near future. Nevertheless, other criteria were also analyzed, such as:

- ease of use,
- speed of deployment,
- fit user requirements,
- customization/flexibility,
- overall functionality breadth,
- support for distributed teams,
- open integration capabilities,
- workflow capabilities.

Aras Innovator\(^11\) was favorable on the cost criteria, but it also ranked well on others like ease of use, customization/flexibility, user requirements and support for distributed teams (it’s a web based application). Its weakness lied on the fact that there is no support in Colombia and had no free integration or automation with the main CAD software. Nevertheless, with a relatively low investment, a set of “connectors” may be purchased to enable direct connection with main CAD systems.

As ARAS is a web based system, it can be accessed by a web navigator with a username and password. The system can be configured and managed by the system administrator account “Innovator admin”, being able to configure users, group identities, permissions, forms, etc. Add-ons were also installed and customized, specially one called “Meeting Manager” which was used to record the weekly meetings that took place during the course’s schedule. Modules for uploading documents and CAD files were also configured. In general terms, all the necessary elements required to control and manage the project were available in Innovator and the flexibility of this software was adequate to adapt it to the course’s requirements.

Aras Innovator\(^11\) enables not only document management but also the management and control of projects. Project-8’s TO-BE Process Model was created to be configured into the system and controlled by students, teachers and the system administrator. Aras Innovator\(^11\) has two different ways of controlling a process; “Workflows” and “Gantt Charts”. Workflow diagrams have activities which have to be completed according to embedded procedural rules in order to complete the process. It’s commonly used for short business processes that may run many times. Since this is not the case of P8, workflows were not used in this implementation.
“Gantt Charts” work with a Work Breakdown Structure (WBS), which allows users to deploy the project into manageable pieces or phases. Each activity in the WBS has a distinct deliverable, start and due date, assignee, and role. The order in which activities are completed is managed by defining predecessors and by the start and due dates given to each activity. This is a flexible way of controlling the process, since each activity can be marked as required or not, and activities can be completed outside of their start and due dates.

When project plans are usually repeated over time, like in the case of a project methodology that is repeatedly followed, Aras Innovator® has a tool called “Project Templates” to create templates that can be instantiated every time a new project is created. Templates help to standardize processes, as well as to provide a reusable structure for similar projects. A project template was created for each phase of the TO-BE process model. These templates are loaded by students to create four sub-projects, each one for each phase of Project-8. They will be standard (as proposed in the template) but groups can edit and customize them when they create their own projects, except for some activities that will be marked as “required”. The activities assigned through projects appear at each assignee’s inbox and the rest of the group, teachers, etc. can check when the activity is completed. A coloured dashboard with Green, Yellow and Red alerts appear on the project plan depending on the punctuality to complete these activities. This helps to keep track of and control the project’s progress and timeline.

4 Execution of the PLM Strategy

The weeks previous to implementation kickoff in the course a lot of planning was done on how selected students, that would enter the course, would be introduced to PLM and prepared to assume this new methodology and novel way of working. This represented a huge challenge because these students had been working with the same manner for more than 3 years. Some of them with the same team partners and none of them had any idea of PLM before this experience. They had only been briefed in some previous courses on concurrent engineering or collaborative design but never formally taught on this matter. It was predictable that some concepts would result hard to comprehend for them, and adopting them could be equally challenging.

The first week of classes, students formed in groups of six. Two of these groups were chosen by teachers to be the pilot groups to work with PLM; groups #3 and #5 (out of a total of nine groups). The time to implement PLM in Project-8 was two weeks; the course calendar starts from the first week of classes and by the fourth week they must deliver the first two phases of the new methodology. In this schedule, quickness to get students ready to work with Aras Innovator®, plan their project and upload documents was imperative.

The introduction was planned on the basis of three tutorial sessions (fig. 2), two tutorial documents, five tutorial videos and a new Project-8 booklet guide. The tutorial sessions consisted in one for PLM fundamentals and Collaborative Design and two sessions on the software. These sessions were backed-up by supporting documents and videos covering the following topics:

1) Getting Started: Log-in window, username and password, working directory, workspace, TOC, Inbox.
2) Project Management: Project Templates, Work Breakdown Structure, How to create projects, Roles, Tasks, Assignees, Predecessors, Deliverables.
3) Documents: How to create new, Numbering and nomenclature, Information to be included, Files (Loading new, Check-out, Check-in, and Get-Copy).
4) Parts: How to manually upload CAD files and create the Bill of Materials (BOM).
5) Meeting Manager: How to fill out a meeting log, participants and action items (meeting activities).
6) Completing Activities: Viewing activity descriptions, completing meeting activities, status and colour indicators, completing project activities.

Figure 2: Aras Innovator® tutorial session
Every software implementation requires monitoring by the system administrator to the initial activities and the user’s adaptation to the system. In this project monitoring was planned to take place during the first three phases of the project, up until the delivery of the Detailed Design phase on the 11th week of classes (leaving the last phase, which was mainly focused to the physical prototype construction). This time was calculated to be sufficient to accompany students during their learning process and solve any doubts or issues that arose. This in turn would provide a good feedback of how successful the implementation was.

Although at the first weeks students presented a lot of technical issues and problems related to the use of the software, by the end of the first month of use students rarely asked questions and very few problems were notified to the system administrator. The role of monitoring became less active in problem solving and more active in observation and process analysis.

As each team generated a project plan for each of the four phases, students should execute these plans and follow their milestones in Aras Innovator® by completing activities and uploading deliverables on time. Fig. 3 shows the System’s operational WBS for one of the teams, clearly identifying deliverables, dates, uploaded files, assignees and roles.

Figure 3: WBS in PLM software for project traceability.

5 Results and Discussion

5.1 Quantitative analysis

Both teams uploaded 100% of the deliverables marked as “required” in all of the three phases. Additionally, Group 3 uploaded eleven extra documents and Group 5 uploaded four. Despite some few exceptions, documents were uploaded with all the required information and in an organized way. Those that initially weren’t, were later corrected. The proposed nomenclature was very helpful to keep documents ordered and made browsing and searching files easier.

Obtained results show that in comparison to the group analyzed in P8 2009-2 (semester before implementing PLM), both groups in P8 2010-1 performed more activities (fig. 4). They also delivered a few more Required Deliverables (fig. 5), but most importantly, these results show that deliverables were reached after following a more structured process.

All of the parts, sub-assemblies and assemblies necessary for the correct reconstruction of the CAD model were made available. This CAD Model was also given in Innovator all the relations between parts and assemblies to create the Bill of Materials (BOM)11. Group 3 failed to upload their CAD model properly. They uploaded the sub-assemblies and defined BOM relations but didn’t upload all the necessary parts to fully reconstruct the model after downloading it. These could be avoided in the future by purchasing automatic CAD connectors.

11 This was tested by downloading the CAD model from Innovator.
One of the key benefits of Aras Innovator® is that students, teachers, clients and all other users of a database have access to all data generated throughout the project. This is a great advance compared to previous Project-8 courses. The analyzed group previous to the PLM implementation had created a common mail account to share files. However, only 54% of the documents they generated ended up being uploaded in this account. Several of those aren’t definitive versions, meaning that the information on them is incomplete or outdated. Every definitive document was printed and put in a binder, but this binder was only retained by one of the team members after the project ended. The other documents are spread on different personal computers that belong to the team’s members. Essential files, such as the CAD assembly model and pictures of the prototype, were only retained by half of the team or less. In comparison, students that used PLM in P8 2010-1 now have a permanent backup of data they uploaded to the system (fig. 7). It’s evident that PLM Software contributes to the preservation and availability of valuable information.

Students presented very different results when their punctuality to complete activities in Aras Innovator® was evaluated. This proves that, despite the standardization and control that Innovator provides, punctuality still remains a personal trait that students must acquire individually to avoid project delays. Nevertheless, thanks to the implementation of PLM this could be traced individually to each student for a more individualized assessment.

One of the objectives of making students plan their projects was to reach a better work distribution throughout the semester. PLM seeks to have more control over this work distribution, not only through project planning, but mainly through permanent monitoring. Project managers can check the project progress at any moment through PLM software like Aras Innovator®, and do the pertinent actions if something is going wrong. Work efforts usually fluctuate; increasing prior to delivery dates and then decreasing after having delivered. Consequently, students in P8 were doing most of their work in the days previous to each of the four deliveries. There was a very unbalanced work distribution throughout the semester, having weeks where almost no progress was made and then, on the week prior to each delivery, students making up for lost time with late night work and lots of stress.

Despite the increase in controls and monitoring through Innovator, deliveries to teachers continued to be priority for students, since they were only graded then. Students continued leaving more work for the week previous to these deliveries than other weeks. However, controls did produce an effect in work distribution, which was more balanced in general than on the prior project course. Controls were made on weekly meetings previous to delivery dates and work effort increased before each of these controls, decreasing pressure and effort on the week prior to each delivery and augmenting results’ quality. Fig. 8 depicts an approximate graphical representation of intended, expected and actual work distribution after PLM implementation.

Quantifying students’ attitude towards work, their social skills and self-discipline wasn’t the objective of this research. However, some qualitative observations can be made based on the observation of the teams that were involved:

- In general, workloads distribution among students has been improved. During P8 2009-2 many complaints were heard between the team members, about others being late or not participating enough in the team’s work. In both groups of Project-8 2010-1 commentaries like these were seldom heard, and students in general were all involved with their projects. A reason for this might be the fact that traceability of student participation is possible in Aras Innovator®.

- Punctuality improved. Despite the delays already mentioned, they were less than on previous periods. Part of this was the cause for the work distribution throughout the semester being so unbalanced.

- The general harmony between team members in the two groups supervised in 2010-1 was better than that of the previous semester. Grudges arose between team members in 2009-2 because they had unequal workloads and also because roles were not assigned
by a group consensus but were rather informally established as the work advanced. Some members resented having been assigned tasks (without having agreed to them) by a member of the group who auto-established himself as team leader without some of the team member’s consent. These problems didn’t occur in Project-8 2010-1 because the activity assignment was done by consensus, with all the members’ participation and the team leaders were chosen unanimously by all team members at the beginning of the semester.

5.3 Student Feedback

One of the most important sources to review the outcome of the PLM implementation in Project-8 was the users themselves. They were asked to give feedback on the adaptation and use of the methodology and software after the first and second deliveries.

Some of their positive comments were the following:
- “The software is easy and handy to use; checking activities and uploading deliverables is easy”.
- “The real benefit I see is at the end of the project where all of the group will have access to the information and documents generated”.
- “PLM has permitted delegating and distributing work better and controlling times for delivery”.
- “This methodology should be slowly introduced in previous Project courses, to integrate this knowledge into the formation of students, and to turn this into a differentiating competence of Product Design Engineers”.

Most of the negative comments were in regards to technical difficulties with the software, mostly due to problems accessing the servers, browser compatibility and connection slowness. Nevertheless, there were also some comments made in regards to the implementation itself:
- “With regards to the PLM methodology the problems have been changing the way of doing things; we aren’t used to this and I often forget to check the activities I’ve been assigned”.
- “More work needs to be done to increase the student’s awareness and appropriation of PLM philosophy”.

6 Conclusion

This work has proved that the implementation of this PLM strategy is beneficial to the education of Product Design Engineering students, amongst other reasons because:
- It stimulated students to collaborate and increased the awareness of their interdependency and commitment to their work;
- It provided them with a tool to address the most recurrent issues in the development of collaborative design projects; sharing and managing information, and planning and having control of the design process in all of its stages;
- It will prepare and qualify them for industrial changes brought by this new technology.

PLM can be as complex and complete as each implementation demands. It can support the design and development of the world’s most advanced airplanes or help a small group of students to improve an academic project development. With the introduction and advances of Open Source PLM tools, more people have gained access to these formerly unreachable technologies and new applications have been created. For developing countries it is imperative to keep up to date with world class technologies and methods for design and manufacturing. This work contributes in this aspect and overcomes the limitations that arise in a pedagogical environment to demonstrate another feasible use for PLM.

References

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