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Technological advances in the last decade have influenced changes in the design and engineering industries on a global scale. Lean and collaborative product development are approaches increasingly adopted by industry and seen as the core of Product Lifecycle Management (PLM). These trends have created the need for new skilled professionals and universities should adapt their curricula in response. There is an increased need for academia to work with industry in order to meet these challenges.

This paper reports on the PTC Academic Research Symposium, held in April, 2011. The topics were centred around understanding the essence of PLM and its impact on design and engineering education. Furthermore, examples of implementing product lifecycle management and collaborative practices in higher education were presented from USA and France. The paper concludes with a discussion of the recommendations made at the symposium for the future development and support of key skills across university curricula.

Keywords: Product lifecycle management; design and engineering education; collaborative product development; university- industry collaborations; new product development; international perspectives

1. Introduction

Parametric Technology Corporation (PTC) is a product development software company, founded in Boston in 1985. They specialise in design and engineering software including solutions for collaborative product development and product lifecycle management. Their main focus is on supporting innovation in engineering and design within all aspects of the product development process but in recent years, they have provided substantial investments in education, working together with universities in order to develop good practices and relevant skills for new product development professionals.

The PTC Academic Research Symposium was held in Boston, in April, 2011. The speakers and delegates explored the issues of integrating PLM in education and university-industry collaborations within an international context. Delegates from both industry and academia discussed current skills needs and gaps in education and debated possible strategies to improve their curricula.

1.1. The development of PLM

It is generally accepted that PLM as a concept began to emerge in the late 1980s as an integrated approach for building a design management system for the automotive and aerospace industries [1]. The complexity of products in that domain together with the growth in global markets and competition posed the need for a better product management system [2].

The modern concept of digital product information throughout the product lifecycle didn't emerge until the beginning of the 21st century [3]. PLM enables the storage, management and sharing of a product's information across different stakeholders throughout its whole life cycle- from concept stage through to disposal [4]. It integrates modelling, engineering, manufacturing and project management software into one collaborative platform [2]. It combines the principles of five key data carriers:

(1) Computer Aided Design (CAD);
(2) Engineering Data Management (EDM);
(3) Computer Integrated Manufacturing (CIM).
(4) Product Data Management (PDM);
(5) Systems Engineering (SE)

CAD and EDM represent the visual specifications and mathematical calculations of a product. Schuh et al. [5] suggest that CIM principles emerged in the 1980s as an early attempt to share product information across multiple functional areas, specifically for computer integrated engineering and manufacturing. However, it is claimed that these early efforts did not fully succeed due to the technological barriers at the time [5, 6, 7]. Modern PLM can be considered the successor to PDM systems [7,8] and the development of related software has been running parallel with technological advancements ever since, allowing for better software capabilities and collaborative sharing of information [9].

In the early 2000s the PLM concept spread through the rest of the engineering community as popularity increased. It is now being adopted by a majority of organisations dealing with product development [9]. There are claims [10] that PLM can increase productivity, maximise product value and reduce cost in organisations. Furthermore it enables better decision making for complex products and brings all the resources together. Product development organisations are known to achieve instant better productivity and cost reduction within a year after adopting related software into their processes [10]. PLM tools are known to improve all stages of the product development cycle including communications, design, and planning [11] and reduce the risks of unforeseen problems at later stages of a product's life [12,13].

According to Grieves [7] PLM is most effective when used in the area of new product development (NPD), where the lifecycle process starts simultaneously with the concept generation of a product. NPD is the process of developing and introducing new products on the market and involves product & industrial design, engineering, manufacturing and even the marketing of the product.

Running PLM alongside NPD entails a strategy based on 'lean product development' first developed by Toyota in 1991. Lean processes aim to reduce waste of resources (time, effort, cost, space, mistakes) through the elimination of unnecessary operations and the creation of a constant workflow throughout the product development cycle [14]. Toyota developed their system through integrating people skills, tools, technologies, and working processes in a collaborative functional approach [15].

Recent trends in setting up global multidisciplinary teams have created the need for collaborative tools in NPD. Organisations are increasingly outsourcing parts of their business across the world as regulatory pressures, competition and product complexity dictate the requirements for new thinking and in particular lean product development [16]. These factors are consequently driving an increased use of PLM processes within organisations on a global scale. Small and medium enterprises as well as giant corporations are realising the benefits of using such processes as tools for enhanced product development [17, 18]. However, it has become clear that the efficacy of such tools is only advantageous within an organisation that fully understands the essence of a PLM strategy and how it works [10,16, 19]. It is in facilitating this that educational institutions are required to address the development of relevant skills amongst young and future NPD professionals.

PLM is a relatively new concept in education, and there is little evidence of it being fully integrated within the design and engineering curricula [11]. This has created a gap in new skills acquisition amongst potential design and engineering professionals [20, 21, 12]. Higher education establishments are faced with a problem of understanding these new skills needs and nurturing their development. It is with this challenge in mind that invited speakers at the PTC Educational Symposium came together to discuss their international perspectives.

1.2. Defining PLM as an organisational strategy

PLM has been defined as an integrated approach that combines people, processes, practices and technology throughout all stages of a product's life cycle [4, 19]. Adding 'practices' to the main elements of lean product development is an integral part to understanding PLM as a strategy for collaborative product development (Figure 1). Companies have been known to confuse processes and practices within their organisational structures. Processes consist of well-defined sets of tasks with clear inputs and outputs of information, for example in using CAD software for drawings designers and engineers have a clear idea of what information they have to input in order to get the finished drawings. Practices, on the other hand, are methods that rely more on judgement and can be adapted to fit within a specific context. Good examples of 'practices' are guidelines and product specification documents, which provide information based on previous experiences in order to aid decision making through judgement. Often practices become processes at a later stage [7].

Established design and engineering processes are often adopted as a method to drive the actions of an organisation in a methodological system. People (skills), technology and innovation are seen to drive these processes. Company practices tend to constantly evolve and improve according to the needs of the organisation but engineers and designers can also improve their own practices through the use of a PLM strategy as it supports the evolution of new approaches towards existing and novel problems, rather than a reliance on repeating the same processes [7].

PLM provides a more holistic overview of a product's environment through the integration of all elements during all stages of a product's life. A representation of the PLM model is given in Figure 2. It includes a central information core available to all functional areas throughout the lifecycle. The information core serves to store and share all relevant information for a product so as to enable collaborative and lean product development through all stages of the cycle. The main functional areas include planning, design, engineering, manufacturing, support, operations and disposal of the product. It's important to note that the ***lifecycle model*** does not end with the launch of a new product; it is implemented throughout its whole life, from cradle to grave.

Historically the generic PLM model was managed through virtual representations as illustrated in Figure 3. Initial ***two-dimensional*** hand and later computer aided drawings provided limited information whilst concentrating mainly on the visual aspects of a product. ***Three-dimensional*** modelling allowed for more detailed geometry information. Clearly the initial phases did not allow for testing, analysis and simulations. ***Virtual environment models*** aim at mirroring the real life product or situation and include more detailed information allowing for testing and analysis.

The nature of the ***lifecycle model***, built upon all previous models, provides information lasting throughout the whole cycle of the product, enabling predictions of future states of the product from servicing and replacing parts, through to termination. The lifecycle model represents "replacing wasted time, energy and material with information" [3]. Organisations involved in NPD are realising such potentials as PLM software is beginning to be more widely adopted by industry.

2. General impact on education and perspectives from USA

Product designs have tended to widen in scope and complexity often expedited by rapid growth in innovation. Businesses are reacting by moving towards cross disciplinary, globally networked teams. Collaborative product development and PLM are now becoming an industry standard [16]. These trends pose the need for adequate skills developments for future NPD professionals. PLM software used for educational purposes can provide environments for simulations that emulate real life situations and prepare future professionals for industry.

There are claims that in order to equip future designers and engineers with relevant skills, universities need to adopt a more holistic approach towards teaching NPD [22]. Students need to be educated in the understanding of reasons behind making decisions rather than simply adopting established processes and procedures [3]. The learning needs to change from learning the *processes* to learning the *practices* of NPD and learning the PLM strategy rather than simply learning the available PLM tools. This would suggest the need to develop relevant approaches and pedagogy in education.

For instance, work by Bennet [23] explored the use of case based learning approaches to support analytical and problem solving skills; and strengthen the links between knowledge and experience in real life situations. Here, students were encouraged to analyse and discuss past examples of real life projects in order to aid their decision making for current design work. This study demonstrated the effectiveness of such approach and also illustrated the need for further exploration. Mioduser and Dagan [24] on the other hand, compared the effectiveness of teaching design processes through functional and structural approaches. The functional approach to the design process included analysis, decision making, exploration and investigation, while the structural approach concentrated on the key stages of the design process such as concept generation and prototyping. Outcomes suggested that the functional approach is more effective in aiding decision making and problem solving and furthermore it supported holistic and flexible models of learning.

Currently there are strong recommendations for moving education towards broader and deeper learning environments in order to provide multidisciplinary knowledge rather than individual specialisations [25, 26]. The shifts towards global collaborative teams in NPD dictate the need for multidisciplinary professionals, who are able to work across disciplines rather than specialising in one key area. Grieves [25] suggested that the following five areas should be of particular focus for universities:

(1) *New composite areas*- ‘Mashing up’ different areas and creating new disciplines according to industry needs, mixing mechatronics with IT, mechanics with electronics etc.;
(2) *New concentrations*- Adapting a holistic approach towards design, concentrating on all aspects of the product lifecycle;
(3) *New inter functional areas*- Design, manufacturing, engineering- all interlinked;
(4) *Inter college collaborations*- Engineering and business, design and business, etc., understanding all aspects of the PLM of a product, from design to supply chain, costs, affordability to disposal;
(5) *New colleges and universities*- Creating new higher education establishments with a specialist development, e.g. College of Technology or Engineering.

It was also suggested at the symposium that universities rethink their core curricula and develop relevant multidisciplinary and analytical skills. Students need to develop a more holistic approach to problem solving and general knowledge towards all stages and areas of product development. According to Grieves [25] this can be supported by:

(1) *Integrating software tools*- Introducing students to PLM software tools from earlier stages would enable the concentration on practice at later stages of education;
(2) *Integrative projects*- Internships and real life projects, incorporating aspects of product lifecycle management can provide relevant skills application in practice;

(3) *Speciality rotations and dual technical tracks*- Collaborations between universities and disciplines can prepare graduates for a multidisciplinary global environment;

(4) *Synchronising graduate-undergraduate programmes*- in order to encourage knowledge sharing.

However there are perceived barriers for the implementation of these recommendations within academia. In the USA, the tenure track for instance poses issues with evaluating and reviewing curricula. As a result some academics can fail to engage with industry and facilitate technological and social advances and consequently knowledge of professional practice and associated teaching methods become dated. The "PhD syndrome", where academics tend to know a lot about a certain subject but lack a broad knowledge in the area, can perpetuate a more isolated view. There is further evidence to suggest that a lack of direct communications between departments and their staff creates barriers that hinder academics in broadening their perspectives[25].

As a leading expert in the area of PLM, Dr. Michael Grieves believes that in order to educate students in PLM strategy, involving processes, practices, and tools, it is necessary to engage them from earlier stages in their university education. Furthermore, the creation of meaningful project experiences, fostering cross-educational initiatives and sponsoring competitive events would result in better preparation for future jobs in industry.

Many of these recommendations were implemented through the development of the Purdue University PLM Centre of Excellence Programme in the USA,a programme directed by Dr. Nathan Hartman, and considered to be a good example of running industry –university collaborations centered on product lifecycle management.

Experience of running the programme has shown that building multidisciplinary and education-industry partnerships are crucial for the future of design and engineering. Hartman states that such collaborations are only successful when there are mutual benefits for all parties involved. These ideas are also backed up by governmental authorities and non-profit organisations such as sector and skills councils who suggest academic-industry and multidisciplinary collaborations within an NPD discipline [26].

The programme at Purdue promotes advancement and implementation of product lifecycle management vision through industry partnerships and public and private grants. Academia and industry work together on real life projects through interdisciplinary collaborations between technology, engineering, science and management. Organisations such as Sandia National Labs, Cummins, Rolls Royce, Boeing, Gulfstream, General Motors, PTC, Dassault Systèmes, and Siemens PLM are involved in the partnerships.

The taught part of the course has been developed by staff from Purdue's College of Technology, in conjunction with Boeing. Both the academic and industrial partners identified an existing gap for learning the practical use of PLM tools [27, 28]. Findings from studies by Hartman et al. and Waldenmeyer et al. [27,28] suggested the need for industry-relevant PLM education, which strengthens students' understanding of organisational structures and procedures in relation to implementing PLM strategies. Furthermore, the majority of existing PLM courses at the time concentrated on learning the processes rather than the practices of PLM and undergraduate internship programmes showed the need to develop more coherent PLM courses [29]. The programme was therefore aimed at understanding why such tools are important to NPD rather than teaching how to use them. It is focused on three main areas using product lifecycle management toolsets - 3D modelling, relational design, and manufacturing process planning. Interactive exercises and group discussions are used in order to maximize understanding of the concepts and ensure a practical, “real world” knowledge.

The certificate programme progresses over three courses (Table 1), each with duration of eight weeks. Material delivery is through two hours of virtual lectures and two hours of virtual lab sessions per week, both run by academic staff at Purdue and industrial partners from Boeing. The nature of distance learning enables a bigger student cohort regardless of their location. The first course serves as an introduction to lifecycle principles related to 3D modelling, the second course in concentrated on PDM tools and the third course focuses on manufacturing planning using PLM information [30].

The programme provides an environment where advanced PLM technologies can be researched, taught, applied and disseminated. The programme’s success is evident from the continuing graduate success, industrial partnerships and research grants [30]. Since the start of the programme in 2008, graduates have found employment in companies such as GE, Boeing, Gulfstream, Textron (Cessna and Bell Helicopter), Nordam, Rolls Royce, Biomet, and Zimmer, with five of them participating in the companies leadership development programmes straight after graduation. The main reasons behind these achievements are the mutual benefits gained by both industry and academia. Such collaborative centres can be a good way to push innovation and research forward and to influence curriculum developments. What is clear is that, in the USA at least, academia can provide an environment for innovation and discovery with focused research and development. Whilst reaching across a broad range of disciplines, academia can do things that industry cannot or chooses not to do. For instance, universities are equipped with research labs and have the relevant expertise, whilst companies do not necessarily have the resources to support these activities. Universities benefit from such collaborations through the opportunities of matching industry skills needs. In turn these could aid in influencing curriculum development, and future research and expertise. Both parties contribute towards the research continuum and the future economy.

The main challenges of the programme are technological and software capabilities such as internet connections and product libraries. These challenges are addressed in their current research projects. The future work of the programme will be concentrated on strengthening academic-industry collaboration practices and establishing product lifecycle management as part of the educational curriculum in USA.

3. Educational perspectives from France

Dr. Benoit Eynard has developed the first complete full PLM preoperational MSc programme, currently running at the Department of Mechanical Systems Engineering in the Université de Technologie de Compiègne (UTC) and the Université de Technologie de Troyes (UTT), France. The programme is concentrated on complex systems, integrating multidisciplinary technologies and cross disciplinary expertise at all cycles of design, analysis and manufacture, assembly and maintenance. The curriculum is based on the fundamental lifecycle model as illustrated in Figure 2 [7].

The main objectives of the programme were initially to address NPD industry needs for PLM and IT solutions to support collaborative and lean product development such as in aeronautics industry [31, 32]. The MSc programme has been developed over the last 15 years through industrial feedbacks coming from mainly automotive, aeronautics and energy industries and also IT vendors cooperating on research and education programmes with UTC and UTT, the companies like Areva, Alstom, CapGemini, Dassault Aviation, EADS Group, EDF, IBM, PSA Peugeot-Citroën, Renault-Nissan, Safran Group, Valeo. After the MSc programme, the need of expert trained at PhD level emerges then now more than 20 PhD research projects have been or are currently supervised by Dr. Benoit Eynard in the field of PLM with various applications and for example latest topics deal with bio-imaging data management, building information management or mechatronics data management. Last, the MSc programme has also benefit of experiences from the AIP PRIMECA network, a French education and research association for integrated design and manufacturing [33]. The network supported by the French government aimed at its creation in mid-80s to promote and help the development of the CIM concept in a network of universities and higher education institutions. During mid-90s the focus was on CAD/CAM and CAE promotion and in 2000 the purpose was on the development of PLM and Digital Manufacturing. Currently, hot topics for AIP-PRIMECA network deal for example with sustainable design, systems engineering or smart factory.

Considering all these backgrounds, the MSc programme on PLM at UTC now consists of two main components; mechanical engineering and information technology:

(1) Mechanical Engineering:
   - (a) Basics of Mechanics
   - (b) Design and Manufacture
   - (c) Computer Aided Design and Manufacturing (CAD/ CAM)
   - (d) Computer Aided Engineering (CAE)
   - (e) Concurrent Engineering and Extended Enterprise
   - (f) Product Data Management (PDM)

(2) Information Technology:
   - (a) Software Programming

(b) Computing and Network Architecture

(c) Operating Systems

(d) Data Base

(e) Collaborative Software

The programme has four specialisations (Table 2) and runs over 2 years. It adopts a *"learning by doing"* concept through global collaborative work for PLM [32].

The curriculum material is emphasised on teaching project management, analytical and problem solving skills through product lifecycle management. Projects progress from everyday objects such as household furniture to complex engineering such as IC engines. This approach has been chosen so students can concentrate on learning key project management and analytical skills at the early stages rather than concentrating on the design objectives. Students are encouraged to work in groups and manage projects primarily through online communication as they progress onto more complex design and engineering issues. The curriculum also involves two compulsory 6 months internships with industry partners further facilitating research and knowledge transfer activities and opportunities for collaborations with industry.

Software enabled communications and CAD solutions are used as tools for implementation. It is evident that these collaborative approaches encourage better design solutions by students and engage in discussions and critical thinking. The effectiveness of the programme is portrayed by the high employability rates of its graduates and the strong collaborative relationships with industry [35]. Many collaborative research projects have been done with the above mentioned companies and a large number of graduated students are working for such kind of companies from the automotive, aeronautics, energy and IT sectors. One of the success stories which can be mentioned is a young doctor supervised by Dr Benoit Eynard and recruited by

Snecma Company of Safran Group. He has been rapidly promoted as leader of the CAD and PLM team in charge of supporting the design and engineering divisions for aircraft engine development.

The future view is in adopting product lifecycle management and lean product development as a standard in all NPD curricula. There is a stress towards the need for PLM education in a broader context between disciplines and future research work will concentrate on PLM for mechatronics and complex systems and the integration of PLM framework for newly emerged subjects like lean product development, robust engineering, sustainable design and systems engineering.

4. Symposium Discussions

The symposium discussions that took place after each presentation were dominated by questions of how to teach more practical skills to future designers and engineers. It was agreed that an emphasis on involving students in real life projects would significantly improve their understanding of the issues in their profession.

It was suggested, that a student's learning of PLM ought to be introduced through a gradual exposure in *"vertically integrated projects"*- starting from simplified tools in the first year of education, followed by an orthodox gradual progression onto more complex PLM methods and strategies. However, experience suggested that the overexposure to tools could produce a 'Black Box' effect. Students introduced to tools from early stages tend to lose the motivation and rationale behind why they should conduct analyses and thereby avoid deep understanding of the concepts.

One of the main challenges identified was in how to encourage students to think critically. In order to develop analytical skills educators need to be careful not to hinder creativity by setting repetitive problems which often result in a loss of interest from students. When setting up problems not only should exercises deal with real world contextual issues but also created to be tackled in a methodological and logically progressive way.

Overall, in order to address the skills needs in industry, educational methods in design and engineering subjects need changing and adapting to move in line with on-going technological, economic and social advances. This could be facilitated by working collaboratively and forming partnerships with other universities, a number of which are already offering the relevant courses.

With regard to software tools, it was suggested that adopting and configuring existing virtual platforms could save both time and money, particularly in the area of product development software. For instance, current research at the Loughborough Design School, UK in conjunction with PTC and the Art and Humanities Research Council is addressing the use of existing web 2.0 technologies to enhance analytical skills amongst product and industrial design students [36]. An online platform to discuss and analyse properties of both existing and new products in a structured environment is currently being developed as part of a doctoral study. Introducing this environment as a tool to enhance analytical skills aims to deliver a positive impact on the skills development of future NPD professionals [37].

5. Conclusions

Teaching technology is only a component of curriculum innovation needed for the future. It would appear that simply teaching PLM tools and processes is not sufficient, but current curriculum advances typically focus solely on this aspect. Teaching also needs to be emphasised on PLM strategies as seen from an organisational perspective. It is apparent from the presented educational perspectives from USA and France that students need to collaborate in teams, engage in real problems and consider their design decisions in line with a number of business initiatives. There is a real need to engage students in a contextually grounded education so that they understand that their design decisions have implications beyond their original purpose. In an effort to address this it is necessary to focus on 3 main themes:

(1) Distributed design teams: Students should be immersed in a distributed and global design process and as such an understanding of PLM, or at the very least the importance of collaboration, is a necessary skill for product development graduates.

(2) Increased product complexity: Students must be made to realize that design decisions are not made in isolation and that there are likely to be wider implications. It would appear that students need to tackle problems that are aligned to business drivers or initiatives. Such as, repeatability of manufacture, design for after sales service and support, or lean product development.

(3) Design for an extended product lifecycle: the increase in environmental, regulatory pressure and embedded software is extending the lifecycles of products. Students must make design decisions on the basis of understanding the implications in the context of a complete product lifecycle.

The educational perspectives presented from USA and France, together with previous work by Bennet [20] and Mioduser and Dagan [21] show scope for adopting various teaching approaches at universities in order to improve the curricula. For instance, the PLM certificate programme at Purdue University, relies heavily on real world projects and industrial partnerships, a concept also explored by Bennet [20]. In contrast, the UTC MSc programme in France has developed its curriculum materials based on the “learning by doing” functional approach, similar to the work done by

Mioduser and Dagan [21]. In all cases the programmes address the issues of collaborative problem solving and multidisciplinary knowledge building needed by the NPD industry.

6. Recommendations

The issues debated at the symposium call for the need to implement curriculum changes to university delivered programmes. The way in which students of new product development are prepared for their professional careers requires an enhancement in key skills. It is recommended that holistic and multidisciplinary approaches are adopted in order to provide students with relevant insights. Furthermore, teaching should be concentrated more on developing good practices related to real life projects rather than repeating prescribed and recycled processes.

The higher education sector needs to work closely with industry to support the development of highly skilled future professionals according to industry demand. The emerging trends of global multidisciplinary teams and the associated skills of cross disciplinary working need to be reflected in the classroom. Knowledge of PLM supported by keen analytical skills is of growing importance and it is recommended to be integrated within curricula. The rapid development of current and emerging technologies needs to be understood and their potential captured for the advancements of learning. This should be facilitated through a policy of increased diversity and collaboration between industry and the educational sector.

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Tables Captions:

Table 1: Product Lifecycle Management Certificate Programme Structure [30]

Table 2: MSc Mechanical Systems Engineering Programme structure [35]

Figure Captions:

Figure 1: Comparison between elements of Lean Product Development [15] and Product Lifecycle Management [7]

Figure 2: Representation of PLM Model [26]

Figure 3: Evolution of Product Virtual Representations