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Teaching Product Lifecycle Management (PLM) with Enterprise Systems*

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Product Lifecycle Management (PLM) is a solution for managing the entire lifecycle of a product from its conception, through design, production, and delivery, to service, and disposal or recycle. While most of the Enterprise Systems—ERP (Enterprise Resource Planning), SCM (Supply Chain Management), CRM (Customer Relationship Management) and CAD (Computer Aided Design) systems—are separate software packages, current PLM solutions draw and integrate various functionalities and tools from these various Enterprise Systems. This nature of PLM poses unique challenges for teaching PLM. This paper shares an experience of developing and teaching a course in PLM with Enterprise Systems. Students carry out a semester-long project of developing new products. At each stage of the new product development process, students learn to apply the state-of-the-art information tools, particularly the Enterprise Systems. In addition to course schedule and content, two instructional materials used in the course will be described: (i) Enterprise Systems Configuration and Business, and (ii) Engineering Change Management. Lessons learned and future plans for enhancement are also discussed.

Keywords: Product Lifecycle Management; Enterprise Systems; ERP; new product development; engineering change management; engineering education

INTRODUCTION

PRODUCT LIFECYCLE MANAGEMENT (PLM) is a system for managing the entire lifecycle of a product from its conception, through need analysis, design, manufacturing, and delivery, to service and disposal or recycle. Current PLM solutions attempt to achieve this objective utilizing Information Technologies wherever possible. According to Stackpole [1], "Product lifecycle management is an integrated, information-driven approach to all aspects of a product's life, from its design through manufacture, deployment, and maintenance—culminating in the product's removal from service and final disposal. PLM software suites enable accessing, updating, manipulating, and reasoning about production information that is being produced in a fragmented and distributed environment." While there are different approaches to realizing PLM, a dominant practice in industry is utilizing Enterprise Systems [2–8]. Common enterprise systems used to support PLM include ERP (Enterprise Resource Planning) [2, 4, 8], SCM (Supply Chain Management) [9], CRM (Customer Relationship Management) [10] and CAD (Computer Aided Design) systems. While these enterprise systems are separate software packages, the PLM draws and integrates necessary functionalities and tools from various enterprise systems. Therefore, the enterprise systems became enablers for PLM and PLM provides a unified framework to utilize those systems in a coherent way toward developing and managing new products. Typical functions that the PLM system utilizing enterprise systems handle include [4]:

- Document management system,
- Product engineering for managing material master, material bill of materials, classification, variant configuration, etc.,
- Integrated product and process engineering,
- Engineering change management,
- Application integration between different enterprise systems,
- Project management,
- Product life-cycle costing,
- Inter-departmental collaboration,
- Inter-enterprise collaboration,
- Quality management,
- Enterprise asset management,
- Environment, health and safety management.

More detail functions of PLM in several stages of product realization is presented by Saaksvuori [6] and shown in Fig. 1. An example implementation of PLM functions in an enterprise system is given in Fig. 2.

There are numerous factors influencing the corporations to adopt PLM solutions in order to remain competitive [11–13]. They are:

1) increasing need for innovation in new products,
2) increasing importance of supply chain management due to globalization,
3) increasing product complexity that demands collaboration of large specialist networks,
4) shortening product lifecycles,

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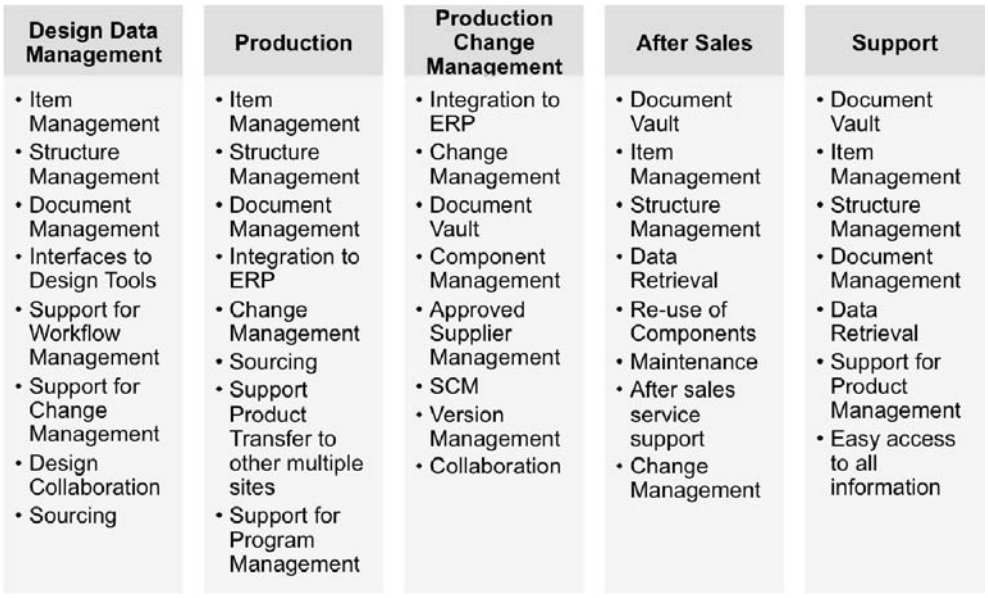


Fig. 1. PLM Roles in Product Lifecycle [6].

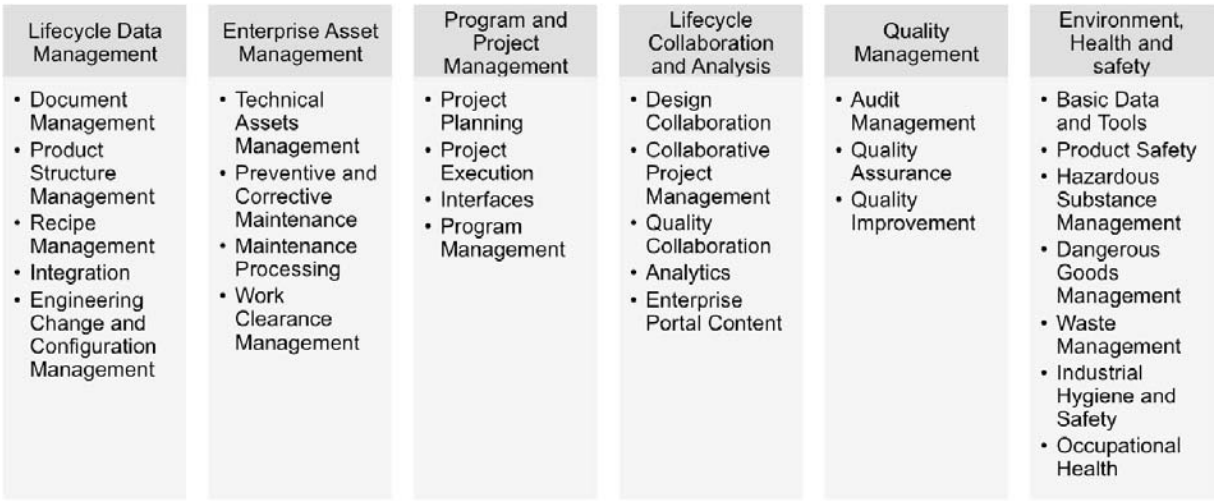


Fig. 2. Example of a commercial PLM and its functions [4].

5) increasing pressure to deliver new product more quickly to the market,
6) increasing awareness on environmental a sustainable issues on products,
7) increasing need for customer intimacy,
8) constant striving for operational excellence.

As the information technologies continuously progress and users are getting to be more sophisticated in using them, PLM becomes an important and essential tool to remain competitive for many companies involving in product development.

The nature of PLM utilizing various enterprise systems poses unique challenges for the academics when teaching PLM with enterprise systems [14]. First of all, there is not enough room for separate coverage of individual enterprise systems. While some of the enterprise systems' functionalities may not be suitable for PLM, others may not easily be recognized as useful for PLM purposes. Available materials for learning enterprise systems are mostly geared toward professional consultants or users in corporate environments. As the cost of a typical enterprise system is in the range of a million dollars, accessibility in universities is another issue. Once the enterprise systems can be accessed, training instructions become a challenge since they are not the subjects commonly taught in universities at least as of now. While these issues demand additional efforts in covering enterprise systems and information technologies, the exposure to product lifecycle issues should not be sacrificed. There should be a proper balance between enterprise systems and PLM.

The most central part of our course is a semester-long project developing new products.

Students are engaged in a project involving most of the important stages in a product lifecycle. While they are developing new products from generating ideas to creating prototypes and devising subsequent deploying plans, the students learn and apply various state-of-the-art information tools such as ERP, Engineering Change Management (ECM) tool, supply chain management systems, and simulation tool. The course concludes with the students' presenting new products and illustrating how supporting systems are used to realize the products.

LEARNING OBJECTIVES

The course was offered for the first time in Spring 2006; at the time of writing three offerings have been made. While this is not a required course for any degree program, it has been a very popular course among the students pursuing M.S. degrees in Mechanical and Aerospace Engineering or in Engineering Management. Most of the enrolled students have BS degrees in Engineering, therefore, have some prior experience in product design, if not the entire product development process. Also, they have background in Computer Aided Design (CAD) and possess skills in using an industry-scale CAD. However, except for a few students, they do not have any prior exposure to enterprise systems or PLM. Students who are in an Engineering Management program have taken and are taking courses from the Business School in the areas of Supply Chain Management and Innovation Management.

Considering the typical profiles of students in the class, learning objectives of this course were set as:

- Understand the characteristics and issues of PLM,
- Develop the ability of utilizing PLM tools for product development,
- Understand a new product development process,
- Enhance the capability of developing new products,
- Develop the ability of managing new product development process,
- Enhance professional skills necessary for new product development projects.

THE APPROACH

The pedagogical approach that the course takes is based on the following three premises:

1) PLM systems draw and integrate necessary functionalities and tools from various enterprise systems.
2) Students' educational experience with PLM materials is more effective when they are actively engaged in an entire product development process.
3) Students' professional skills can be enhanced when appropriate guidance and feedbacks are provided to them when they are engaged in the product development project.

Enterprise systems and PLM

ERP: The Enterprise Resource Planning system is an enterprise information system designed to integrate and optimize business processes and transactions in a corporation. The ERP is industry-driven concepts and systems, and is universally accepted as a practical solution to achieve integrated enterprise information systems. Central components in production planning and materials management that are essential for PLM, include bills of materials, material master, configuration management, etc. However, other functions in ERP are also closely linked to PLM. For example, financial and controlling components can provide necessary costing information at various stages of product development. Modules in quality management, project management, human resource management are useful for PLM as well.

CRM: While satisfied customers have been a core factor for any successful corporation, CRM (Customer Relationship Management) in the context of enterprise systems refers to an integrated information system handling many of the traditional marketing functions and enabling additional capabilities of interacting with customers. Major supports that current CRM systems offer include:

1) marketing through analysis of market and customers, marketing planning, campaign and promotion, lead management, etc.,
2) sales through sales planning, opportunity management, product configuration, quotation and order management, etc.,
3) sales order processing through availability checking, payment processing, shipping, billing, claim management, etc.,
4) customer service.

Some of the obvious functions of CRM that support PLM are market and customer analysis, opportunity management, product configuration, claim management and customer service.

SCM: The original ERP systems were developed to integrate and execute operations and functions within a corporation. As internal integration has been achieved, many corporations are now pursuing efficiency through external integration with supply chain members. The concept of Supply Chain Management (SCM) is far wider. SCM in the context of enterprise systems refer to an information system that enables companies to achieve the goals of supply chain management more effectively. Some of the typical functions included in SCM systems are demand management and planning, supply chain planning and scheduling, transportation planning and scheduling, avail-

ability checking and promising, etc. When a product is developed collaboratively and/or produced and assembled across the supply chain, SCM is essential for PLM purposes.

SAP Alliance Program

Enterprise systems are large packaged and integrated software. While underlying models and algorithms may be covered through lecturing, students do not develop a full understanding of these systems unless they are given opportunities to work with them directly. This can be one of the biggest challenges for universities because accessing these systems is expensive and learning curves are steep. As a way to resolve the issue, a few leading software companies developed university-industry cooperation programs. For example, a leading ERP software company, SAP established the SAP University Alliance program in 1997 [15, 16] through which a full scale ERP system is provided for research and instructional use. While the beginning of the program included the ERP system only, now it makes additional enterprise systems such as CRM, SCM, and Business Warehouse available to alliance members. In addition, members of the alliance program develop and share instructional materials appropriate for university education.

Syracuse University began the preparation to become a University Alliance member in 1999. Officially, the alliance program was launched in 2000 as a joint effort between several colleges and schools such as LCS College of Engineering and Computer Science, the Whitman School of Management, the School of Information Studies, and the University College (UC). The program at Syracuse University has steadily grown and now requests over 1,000 student accounts per year from SAP to use in a variety of courses.

The course described below fully utilizes this opportunity by providing each student with individual accounts on ERP, SCM, and CRM systems. As the actual systems reside in a competency center and Syracuse University gets their services over the Internet, students are able to access all the systems anytime and anywhere as long as they have access to a client computer with an appropriate graphical user interface (GUI) installed.

New product development projects

The most central part of the course is a semester-long project for developing new products. Students carry out a product development project going through most of the important stages in a product lifecycle. During the product development process, students learn and apply various tools such as ERP, Engineering Change Management (ECM) tool, supply chain management systems, and discrete-event simulation. The course concludes with the students' presenting new products in the form of prototypes and illustrating how supporting systems are used to realize the products.

The course begins with invoking students' interests and imaginations in new product development by showing and telling them about unlimited opportunities for new products. Along with showing many innovative ideas that turned into new products, a segment of "Nightline" on IDEO's product development process is played to students. Then students are asked to generate many ideas for new products 'to make other students' lives better.' Within the first two or three weeks of the course, new product ideas are finalized and project teams are formed for the products. From here on, the project teams go through a series of product development stages such as identifying customer needs, concept generation, concept selection, product design, prototyping, design of manufacturing processes and systems, costing, and a product launching plan. Lectures and case discussions accompany each phase of the new product development process. The students present their intermediate results at the conclusion of each major stage of the product development process.

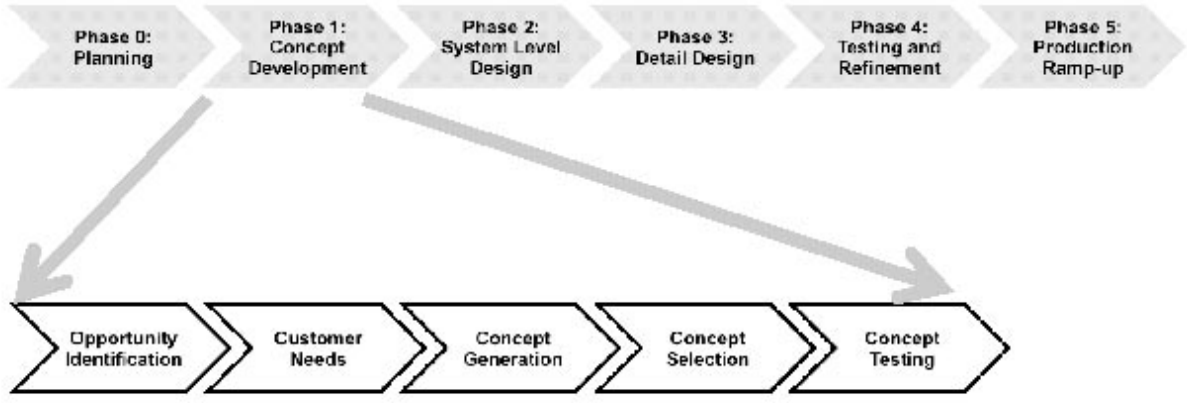
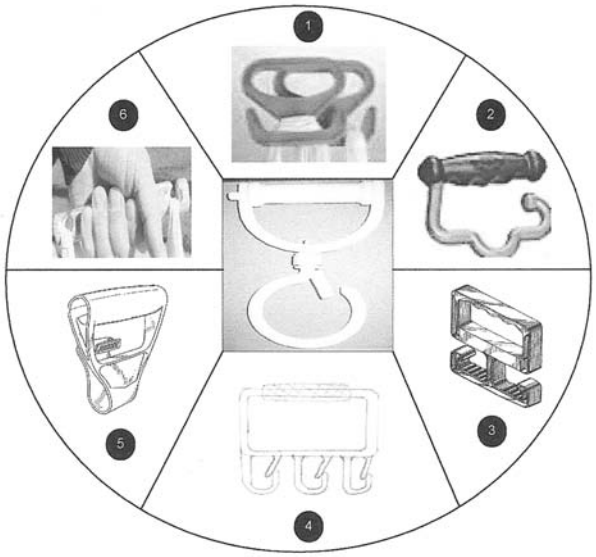


Fig. 3. Product development stages.

Fig. 4. Student project example (C-Handle).



Features	1	2	3	4	5	6	C-Handle
Firm Grip		✓			✓		✓
360° Rotation							✓
Bag Removal Sequence							✓
Light in weight	✓	✓	✓	✓	✓	✓	✓
Low Cost			✓	✓		✓	
Weight Balancing	✓		✓		✓	✓	✓
Aesthetically Pleasant	✓				✓	✓	
Compatibility	✓				✓	✓	✓
Portability	✓	✓	✓	✓	✓	✓	✓
Weight capacity>30lbs.			✓		✓		✓

Fig. 4.1. Market study and comparisons of existing products.

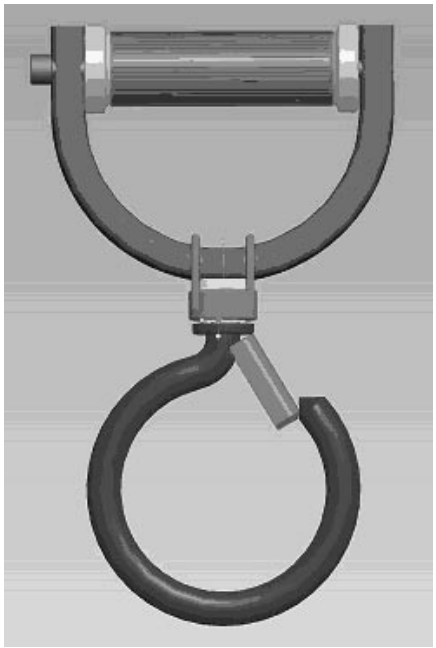


Fig. 4.2. 3-D Rendering of C-Handle's CAD file.

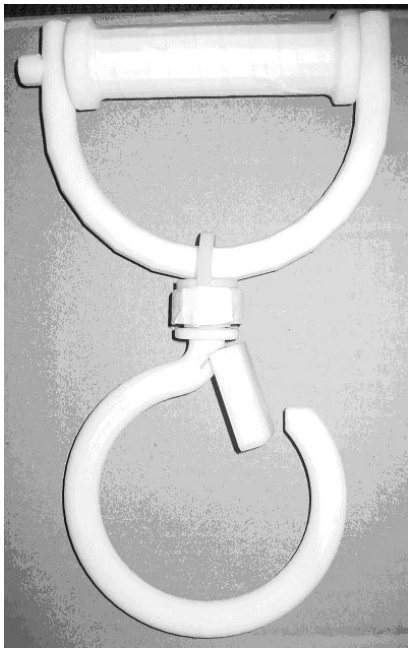


Fig. 4.3. Prototype created using 3-D printing prototyping machine.

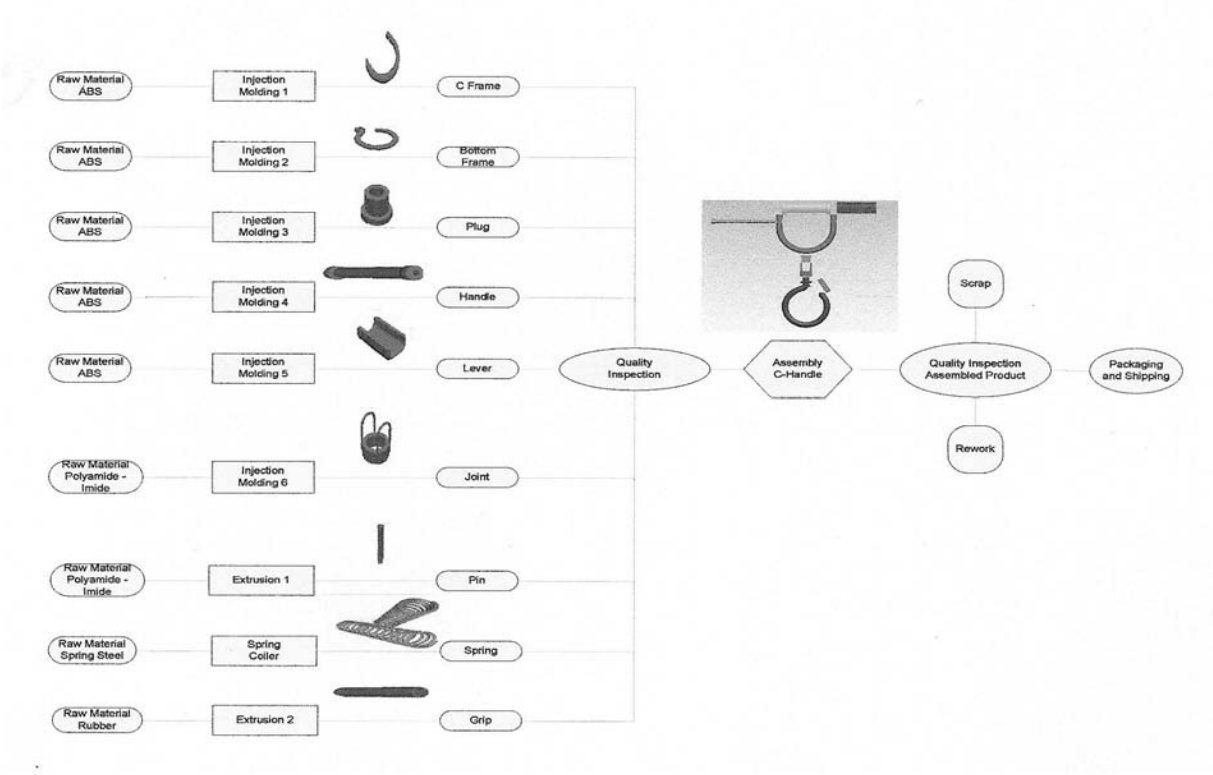


Fig. 4.4. Part explosion and manufacturing plans.

The new product development process adopted in this course reflects a structured approach as illustrated in Fig. 3.

In addition to new products, students are asked to show how enterprise systems or information technology tools are used to support their product development efforts. While there is no requirement for a particular 3D CAD system for product design, most of the students use "Pro/ENGINEER" package by Parametric Technology Corporation as it is available at Syracuse University. A few students also used "AutoCAD" by Autodesk, Inc. and "SketchUp" by Google Inc. Students are also required to develop detail manufacturing processes and systems to realize their products. Use of simulation technologies is encouraged to prove their chosen processes and systems. "ARENA" discrete-event simulation package is available for students' uses, so most of the students developed simulation models for designing their manufacturing systems. No formal PDM (Product Data Management) system is currently available for the students' projects. However, students are encouraged to use any available electronic tools to manage all the digital data and information. Such means include emails, blogs, course web management system, and ERP system, just to name a few.

On average, students reported to have worked 6–10 hours per week beyond class time. An example of past students' projects is provided in Fig. 4. This particular product was a grocery back carrier, called C-Handle.

TEACHING MATERIALS

Two teaching materials utilizing enterprise systems were developed by the author. The first one is to educate students on ERP that is a foundation for PLM. The second deals with an important function in PLM, called Engineering Change Management.

ERP configuration

An ERP system is a very large software package covering a wide range of a corporation's internal transaction requirements. As a result, providing a meaningful hands-on experience with the system within a relatively short period has been extremely difficult. Particularly, since the essence of the ERP system is its integrative nature; partitioning an ERP system into several modules and teaching them separately defeats the purpose of teaching an integrated information system. Bearing this in mind, the author developed an educational material that enables students to construct an executable ERP system using SAP's product from scratch. This material was developed with the following goals:

1) To provide students with the least possible number of exercises while exposing them toward the entire range of major ERP functions.

2) To make the material clear enough even for students with no prior experience in SAP ERP.
3) To enable students to configure their own ERP system, within 6 hours when working in teams.
4) To enable students to perform realistic business process simulation.

The exercise consists of nearly 200 exercises and is organized into six departments:

1) Financial management
2) Production management
3) Supply management
4) Sales management
5) Controlling
6) Configuration support.

While the departmental structure doesn't have much meaning in an integrated information system such as ERP, the above organization into several departments enables students to start with typical understanding and move toward true appreciation of an integrated system when they finish all the exercises. For example, numerous exercises that are mutually dependent are situated in several different departments. Therefore, unless there is close communication between departments, the configuration exercise can't be completed properly.

For each department, the exercises are divided into three parts. The first part is for configuring an empty ERP system. The second part contains exercises needed to input master data into the ERP system. Once these two parts are completed in all of the six departments, students do the third part that is for business simulation. In carrying out this part, the students learn the workflow of typical processes involved in ordering, selling, producing, billing, etc. Also the third part verifies whether the first two parts are implemented without an error, since students can do the third part without completing the first two parts correctly.

Configuration exercises have been used successfully in numerous engineering and business schools in USA, Spain, Korea, and Turkey. The first page of the table of contents is provided in Fig. 5.

When product development projects progress to the point where a Bill of Materials (BoM) for a product can be created, the first major exercise on ERP takes place. In addition, students learn a number of important concepts in PLM such as types and uses of BoM, material master, product data management, information required for cost estimation, and how to connect product information in ERP to other types of enterprise systems such as CRM and SCM. Students are also challenged to think beyond typical usage of ERP to support PLM.

Engineering Change Management

Engineering change normally refers to a change in design of a product or components [17, 18]. While numerous changes are to be made during a product development process, the engineering changes are those occurring after the design of a product is completed and the product is introduced to the market. The reasons for requesting engineering changes are many including obsolete materials, malfunctions, customer complaints, low-cost alternatives, etc. Engineering changes used to be considered as a disruption to normal manufacturing activities, thus as something to be eliminated. However, firms discovered that engineering changes are a normal part of their business and cannot be completely avoided. In fact, some engineering changes can bring beneficial results to the firms. Engineering change is inevitable in manufacturing companies. In fact, trying to eliminate it completely is both undesirable and unrealistic since this would inhibit the chance to improve.

To illustrate the Engineering Change Management (ECM) process using enterprise systems and to provide hands-on experience of ECM, instructional material has been developed by the author and his students. This material is closely related to the first ERP Configuration as students are implementing and executing ECM process on the same part used in the ERP configuration exercise. About 80 exercises in four stages are included in this material. Students learn how to request engineering changes and approve them. Once they have been approved, they need to follow a clearly defined protocol to modify all the affected attributes of a part. After the engineering change is complete, students verify the correctness of the change.

In addition to going through the exercises, students are challenged to think about possibilities of using engineering changes for enhancing PLM activities. Some of the discussions are on how to take engineering change requests as an opportunity to generate new product ideas or to redesign a product, how to distribute a fixed set of resources between new product development and engineering change management, how to solicit engineering change requests, how to decide between new products and engineering changes, and how to do ECM over supply chains. While these discussions have not been implementation exercises, students were able to learn the nature of ECM from the exercises.

COURSE CONTENT

Other components of the course are lectures and case discussions. The lectures provide principles and tools for each stage of PLM. Therefore, they are placed in the schedule in close coordination with the product development project. To complement the lectures, a number of business cases are adopted and discussed in class. As more than a half of the enrolled students tend to pursue M.S. Degrees in Engineering Management and the remaining students are also interested in management aspects, using business cases has been

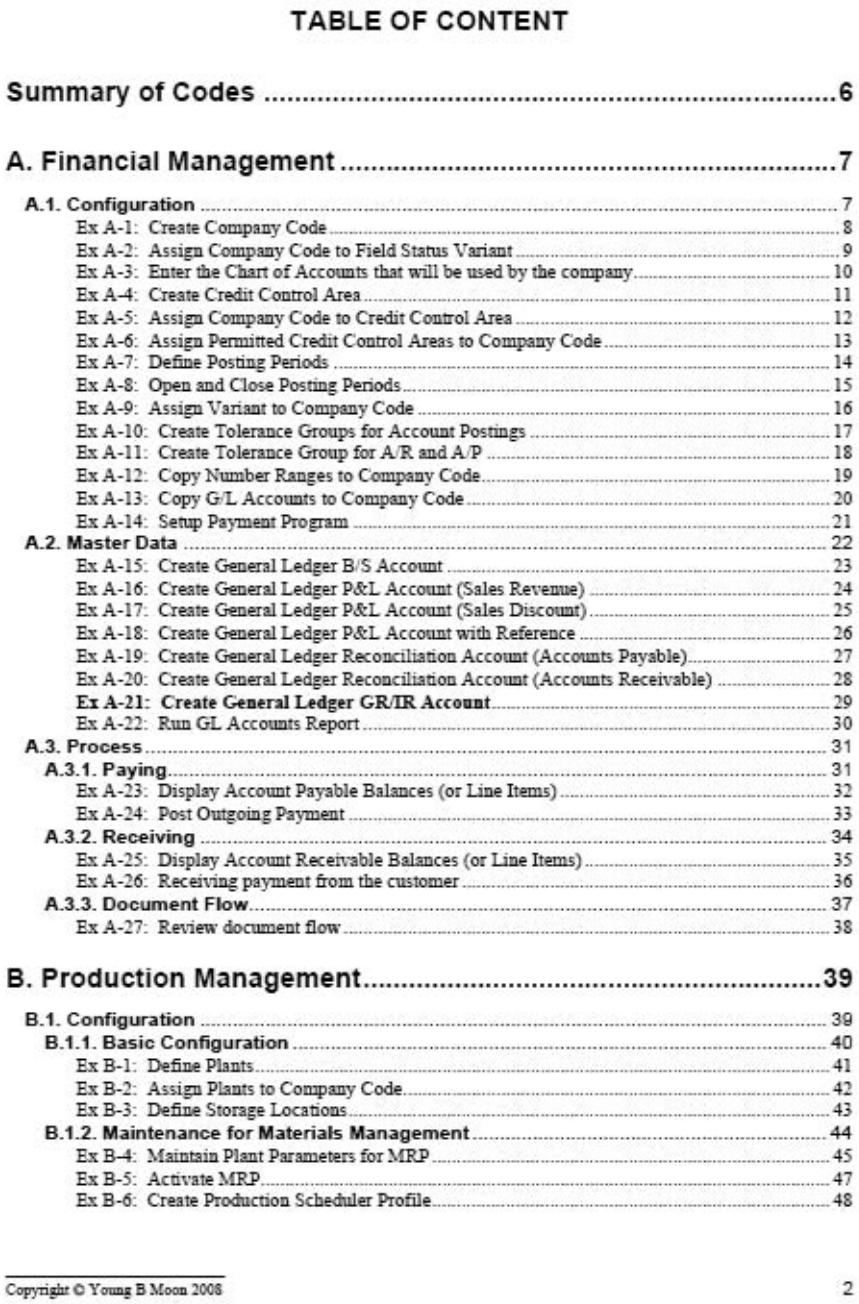


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Fig. 5. ERP configuration teaching material.

successful and well received by students. Examples of the cases used are:

- Bush Boake Allen: to discuss how to utilize a state-of-the-art information technology tool to solicit customer needs, how to justify its use, and what are its drawbacks.
- Hewlett Packard: to discuss the project management related issues when innovative new products are being developed, and success and failure factors for new product development projects.
- Team New Zealand: to discuss the role of computer simulations in PLM and how to make decisions on the balanced use of physical prototypes and computer simulations.
- BMW AG: to discuss the role of industrial design in new product development and the pros and cons of handling that role through information technology tools.
- Siemens AG: to discuss how to manage product development projects globally, how to use information technology tools effectively for such projects, and considerations for cultural differences in collaborative projects.

So far, all these business cases have been adopted from Harvard Business cases. While these were

1	Introduction	Opportunity Identification
2	Opportunities	Customer Needs/ Concept Generation & Selection
3	Concept Proposals	Case: Bush Boake Allen
4	Research Proposals	Case: The Flight of the Kittyhawk
5	Product Proposals	Case: Team New Zealand
6	Enterprise Systems	ERP Configuration Lab (i)
7	ERP Configuration Lab (ii)	
8	ERP Configuration Lab (iii)	Product Lifecycle Management (i)
9	Simulation (ii)	
10	Simulation (iii)	Case: BMW AG
11	Progress Reports (Prototypes)	Target Costing / Patents
12	Product Lifecycle Management (ii)	Case: Siemens AG
13	ECM Lab	
14	Project	Presentations

Key:

PLM Labs
Lectures
Cases
Presentations

Fig. 6. Course schedule.

originally written for business majors, there are ample topics and issues that mechanical engineering and engineering management students can relate and contribute to.

Supply Chain Management (SCM) and Customer Relationship Management (CRM) tools are also introduced and available to the students. While there is no mandatory exercise utilizing these tools in the current course offering, students are encouraged to use these tools for their project as appropriate. Normally students taking this course have prior working knowledge of one of the CAD packages, so no instruction on CAD is necessary. However, students have been motivated enough to learn and use new functions of a CAD system such as animation and finite element methods.

Another important tool that students learn and apply is system simulation. As product design is being completed and a major portion of the product's manufacturing processes is determined, students embark on development of a discrete-event simulation model of a manufacturing system where the product will eventually be produced. Students first develop detailed manufacturing processes, then experiment with various configurations of their manufacturing systems. Students have opportunities to assess relative advantages of each configuration before they choose one. Along with simulation at the product level, that at the manufacturing-system level add a dimension to PLM.

While there have been changes from one year to another, several guest lecturers have been invited to give their perspectives on PLM. Particularly, those who use enterprise systems to support PLM in industry, also faculty members from other disciplines such as marketing and industrial design have broadened our students' understanding of PLM.

A detail schedule of the course describing how all of these are coordinated is provided in Fig. 6.

CONCLUSION

The importance of PLM in industry is steadily increasing, so is the demand for engineering graduates who are properly trained in the subject. However, there are numerous difficulties and challenges in teaching PLM in universities. The course described in this paper illustrates an example of

addressing some of the issues so that other educators may start offering similar courses or, if encouraged, develop their own courses.

While there are no quantitative data available to assess the effectiveness of the course mainly due to a limited number of offerings so far, there are numerous indications that the course is at least set in the right direction. First of all, the course has been extremely well received and subscribed by students and they seem to enjoy taking the course. As a result, they tend to study more and expend more effort. As delivering their final projects is not possible without acquiring and demonstrating specific skills and knowledge, final results of their new product projects are a definite proof of achieving the learning objectives. Another indication is positive responses from the industry in terms of hiring our graduates who possess PLM knowledge and skills. As the course continues to be offered, a plan is devised to collect more objective data for formal evaluation of the course's effectiveness.

Through new product development projects, students have demonstrated their creativity and innovative ideas. From three offerings of the course, a total of twenty new products have been conceived and developed. While most of them are of high academic quality, some of these products warrant further commercialization. Developing short modules for teaching basic entrepreneurship is currently under way.

In future, concepts in Service-Oriented Architecture will be introduced and appropriate instructional materials will be developed, in order to reflect the current status of enterprise systems. Also, joint offering of the course with international partner universities is being discussed.

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