GLOBALIZATION AND PRODUCT DESIGN CURRICULUM IN ENGINEERING PROGRAMS

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Abstract

Today products are manufactured and marketed globally and supply chains have dominated the manufacturing landscape. Most companies have much wider product ranges. These companies are introducing new products more quickly with a sharp focus on the market. As we move into the new century, we need to incorporate these improvements to develop truly agile product development process. There is trend towards a multiplicity of finished products with short development and production lead times. An agile approach to manufacturing faces the reality that we must serve customers with small quantities of custom designed parts with perfect quality, 100% on-time delivery, and at very low cost. Companies are forced to organize themselves in such a way that high quality products can be developed very quickly in response to customer requirements.

Globalization of the product design and manufacturing requires its practitioners to master engineering methodologies, cultures, and languages from more than one country. The Internet enables manufacturers to design and produce wherever these can be done most efficiently so that any one globally can be a competitor. Studying best practice used by others and benchmarking them has become a standard procedure. The importance of globalization has also been stressed in the engineering criteria EC 2000 of ABET. The techniques listed in this paper are used by world-class companies to guide the design, and development of high-quality products in a step-by-step manner using analytical tools and case studies. The paper highlights how a typical product design course should include topics on building a product team, new product creation strategy and process, creative design techniques, impact of globalization on the principles of design for manufacturing, design for disassembly, and ergonomics. In view of the development in lean manufacturing and information technology, emphasis on value stream mapping and its influence on product development are important. The paper concludes by summarizing the special topics that need a focused approach to product design.

Introduction

During the Second World War, quantity was the greatest concern to the user and the industry had to respond to the demand. From the 1970s, the emphasis shifted and manufacturing had to respond to demands for improved quality. The industries developed basic knowledge of the processes as well as manufacturing logistics, which was followed by expanding electronic industry and factory automation. By the mid 80s, investment in automation and total quality management began to show considerable promise. Rise in computer industry led to enormous growth in both hardware and software. Through the use of computer technology, flexible automation integrates product, process and management information into a single interactive framework, which reduces the number of operations. By late nineties, Internet based manufacturing was the natural extension of these paradigms, where an enterprise could respond to delivery, quality and variety. The new generation of manufacturing companies are able to identify and supply each customer's unique requirements with an integrated set of products and services that fit cost, timeliness and functional requirements and that are flexible enough to evolve with changes in the customer's needs. To do this, companies are developing core competencies, organizational structure, and business practices.

New Generation of Manufacturing

When we review the science of manufacturing, it can be concluded that the activity of manufacturing is much more than the machining of metals or the etching of wafers for semiconductors. In the new competitive environment of manufacturing today, product cycles are short and markets are fragmented, thus making quality and speed critical. The automation of machines - a pervasive technology impacting every dimension of manufacturing. Microelectronics, MEMS, nanotechnology, sensors is contributing to the development of intelligent products. Photonics, light processing electronics and instrumentation revolutionizing the communication industry. Flexible automation system, intelligent processing of materials, precision engineering, and technology of rapid prototyping that assists in the creation of a product is also noteworthy.

The new generation of manufacturing companies is able to identify and supply each customer's unique requirements- products and services that fit cost, timeliness and functional requirements and that are flexible enough to evolve with changes in the customer's needs. Companies are developing core competencies, organizational structure, and business practices. As a result, managers of the future must be more skilled at developing and implementing manufacturing strategies in totality, rather than as a series of isolated, sequential steps. The measure of manager's ability to react fast to sudden, unpredictable change in customer demand for its products and services and make a profit is very important

Changes in Product Development Concepts

The price of a product, which is marketed globally, is dictated by world economy. Successful companies are expected to be the ones that use the best practices of engineering approach, by

focusing on product and process delivery system and knowing how to transform process innovations into technical success. Some have moved the hard-core product design and manufacturing from high wage locations to places where they can be generated inexpensively. In a global economy that is becoming more and more integrated, a shift is taking place in many companies. These companies are also undertaking actions for survival to generate products that are globally competitive in a changing environment. Many have formed partnership with suppliers, customers and international partners.

Technological innovation in manufacturing has been influencing the manufacturing environment and continues to influence the factories of the future. Manufacturing technologies include more than factory automation alone. A systematic approach to the introduction of these technologies, along with changes in management practices, is essential to generate potential benefits. To achieve these benefits, manufacturers must implement advanced manufacturing technologies and management practices throughout their operations. Manufacturing will require highly skilled work force that can be very productive. Equipment has to be flexible with high emphasis on quality. In addition, highly accurate equipment will be needed which will be flexible to rapidly changing set up. Companies that do not move in this direction will become increasingly noncompetitive.

Underlying the future of the manufacturing environment of tomorrow, are the strategic technologies that we recognize today as playing an important role in our planning in industrial sector. The industries that are going to adopt these practices will be expected to make changes in policies and programs that can reach these goals. They also require collaboration among government, industry, labor and educational institutions. To achieve this partnership, manufacturing companies must make organizational changes that will support the new company culture.

Trends in Engineering Education

Several studies have shown that employment in research and development high-tech industries are shifting dramatically toward service industries. The demand for high-tech workers is shifting to jobs more involved with service creation than production of goods. Trend is towards more engineers in jobs related to production of services compared to production of goods. Considering employment in R&D – intensive high tech industries as a percent of all non-farm, manufacturing, services, mining employment, - only R&D intensive services employment gained. (*Monthly Labor Review (Luker)*

Consistent with the overall shift toward R&D intensive services from manufacturing, almost three quarters of new production and non-supervisory occupations were in R&D intensive service industries. Demand for high-tech workers shifting towards occupations that have more to do with the production of services than production of goods
A survey of engineers under 30 in small private companies indicated (1):

- 19% are in companies with < 100 employees
- 8% are in companies with < 25 employees

- 40% are in companies with > 5000 employees

The Trend is towards more employment preference in small companies.

Major studies organized by National Science Foundation (NSF) and American Society of Mechanical Engineers (ASME) has indicated that a change in engineering education is needed and it is taking place. The period 1945-1960 is known as the era of hands-on education and use of handbook, physical experiment. This was followed by the math-based, theoretical, computer oriented era of 1960-85. There had been more clamors for reform and broader understanding of the context of engineering practice during 1985-2000. There was a consensus for the need for improvement without weakening what we have done in the past is evident.
Table I shows the differences between two models:

Analytical Science Model, 1960-85	Integrative Model, 2000
Vertical thinking	Lateral (functional) thinking
Abstract learning	Experiential learning
Educationalist	Integration-Connecting the parts
Develop order	Correlate chaos
Understand certainty	Understand certainty
Analysis	Handle ambiguity
Research	Synthesis
Solve problems	Design/Manufacture/Process
Develop ideas	Formulate problems
Independence	Implement ideas
Technological –Science base	Team work
Engineering Science	Societal context/Ethics
	Functional core of engineering

Table 1. Analytical Model and Integrative Model

Characteristics of 21st century education

Our graduates must be educated to understand the functional core of the engineering process. They should be able to analyze, synthesize and formulate problems and solve them, become adept at group problem solving strategy. They should be able to recognize and contribute to the relationship of the engineering enterprise in the socio-economic context. The development of the motivation, knowledge base, and intellectual capability for career-long learning is important.

Some of the approaches to enable students to learn how to "work smarter" are:

1. Interdisciplinary, vertically integrated real design projects
2. Collaboration with colleges of arts and sciences, business and medicine in curriculum development
3. Coupling between engineering technology & engineering programs that emphasize complementary and evolving roles in the workplace
4. Experiments in professional master's degree
5. Recognition of educational research and teaching as valuable scholarly activities

6. Provide two-way transfer of knowledge between universities, industry and government laboratories.
7. Target lifelong learning and graduate engineering education

Impact on Product Design Curriculum

Design activity involves a broader range of disciplines:
The corporations have now realized that better and more functional products can be developed if the design team involves more expertise than just engineering alone. This allows the use of team approach and concurrent engineering practices.

Globalization of engineering practice and increased competition:
The engineering practice is more global and to be successful, engineers must understand and have a good appreciation of the culture and history of the negotiating partners. At the same time the global competition is increasing and the international partnerships among firms are growing to meet these challenges. This shows that the engineering education is now more global in nature

Concept-to-product time shortened:
It is said that the useful life of a product is only until a better product emerges in the market. The designers have to reduce the cycle time for product design and build the best in available time

Companies narrow their focus to the core business:
Companies have realigned and narrowed their focus to selected products that have a niche market

New technologies emerge at a quickened pace:
The exponential growth in computing and information technology, E-manufacturing, knowledge management had changed the way engineering design and manufacturing is done.

Others:
Companies realize that better & more functional products can be created if we have better, multifunctional teams. Constantly changing work environment demands interpersonal skills. Changing demographics, success in serving diverse customer base requires diverse workforce.

Changes in Engineering Practice

The design and development of a product invariably involves considerable investment of time, effort, and money. It is essential that a new product is thoroughly examined and reviewed before it is presented to the public. A company's credibility, reputation, and finance rest on the launching of each of its products. The fundamental questions a product designer has to look into are the Why? What? How? Who? and When? pertaining to the product. The goal is to develop the product that is best for function, manufacturing, reliability and servicing. This is the ideal design, but one that is difficult to achieve. Thus, the process has to be managed in steps, which ultimately have to be integrated successfully.

Table II shows a typical curriculum that can be used for product design courses. A typical product design curriculum should make the students familiar with the steps in creative product design starting from concepts to production and marketing. The students should be introduced to various product redesign techniques using case studies. They should learn about issues of design for disassembly, reliability, and maintainability and different tools that can easily have an impact on the new product development process.

PRODUCT DESIGN – Product Realization Process	Design Approaches Why Should Promising Products Fail? Building Blocks of New Product Design Comprehensive Strategic Plan Impact of Design on Environment Concurrent Engineering in Design Impact of Modern Manufacturing Tools and Techniques
PRODUCT DESIGN – Conceptual Phase	Design Concept Development Methodology Concept Selection Using Function Diagram Function Analysis for Product Design Understanding the Customer Customer driven Product Development Axiomatic Design Method Inventive Problem Solving
PRODUCT DESIGN - Design and Assembly	Design for Manufacturing Methodology Impact on Manufacturing Processes Systematic Process Selection Manufacturing Processes and their attributes Design for Disassembly Design for Life Cycle
PRODUCT DESIGN – Tools and Techniques	Tools of Optimum Design Learning Curve Analysis Robust Design and Process Capability and Control in Product Design Failure Mode Effects Analysis Product Modeling using CAD/CAM
PRODUCT CREATION – *Streamlining the Process*	Workplace Design Product Line Design Based on Variation, Volume and Optimization Ergonomics in the Industrial Workplace Managing Product Development Building Successful Product Groups Group Interaction Self Directed Working Group

Table II ***Product Design Curriculum***

Focused Approach to Product Design

Focus on the Customer

World-class manufacturers have placed great emphasis on being close to the customer. Having the customers fully participate in the design of his product can significantly enhance the design process. The customers bring their design skills to bear of the project and your company adding its production skills into the equation. In some cases the suppliers and outside process vendors can also be integrated into the design process so that the product is designed to meet the customer's needs very effectively. This close cooperation allows for the development of service-rich products that can evolve over time, as the customer and the company work closely together. The products may be designed to not only meet current needs but also to be reconfigurable to meet the customers' future needs. Attention is paid to configurability, modularity, and design for the longer-term satisfaction of customer requirements. The advantage of close relationships with the customer is that they help ensure that the product being developed really meets customer requirements

Focus on Concurrent Engineering

Key concepts of new product development include customer orientation, major decisions, up-front, concurrent development of product design and production processes, using cross-functional teams, and use of efficient design and manufacturing techniques. The "voice of the customer" must be translated into product requirements that meet the needs and expectations of the customers. This is an important step and must be done in the beginning. Customer satisfaction is a primary factor in the success of a product. These expectations can be summarized in four terms: better quality, reliability, free maintenance, and lower price. The product development process uses the customer expectations as an input and concurrent engineering as a design approach.

Focus on the Environment

The innovation of new products has been exerting a more serious impact on our life and environment than ever before. Unfortunately, these technological changes have not always taken the impact on the environment into account, in the enthusiasm of maximum profit and efficiencies, and thus, become one of the major causes of environmental crises. The global nature of product design and usage has enhanced the relationship between the producer and the user. It is logical to conclude that the design stage has to be enlarged, first in terms of the ecological impact of the products, and second, in terms of the dualistic mental framework in which the design activity is viewed. Ecological effects in product design are an important area of concern. Just as we cannot put up a plant without preparing an ecological impact statement, a product needs to be studied for its environmental impact before it is put on the market.

Focus on Modularity

Modularity is an important consideration in maintenance of the product. Modularity allows the product to be repaired easily since parts are removed and replaced in modular form. As a result, the re-cyclability of these modules must be considered during the design phase. This also brings the life cycle of the modules into question. In general, the life cycle of any product can be broken down into four areas of interest:

1. Design and development
2. Production
3. Operational Use and maintenance support
4. Retirement and material disposal

It is becoming increasingly obvious that during the design phase, engineers must think about modularity. With *modularity*, some of the devices from existing designs can be utilized for the newer designs. The short technology life cycle of many of the functions in these products combined with customer demand for a wide variety of features necessitates that product designers optimize the modularity of components for manufacturability and serviceability.

Focus on Materials and Management in Product Design

The rapid developments currently taking place in certain research and development fields will have tremendous effects on product design. Wide spectrums of information technologies, biotechnologies, along with other new materials are influencing the market significantly. The engineering community is currently in the process of developing new materials with special characteristics, to replace more familiar materials. For instance, these materials are known for their power to weight ratio in engines and their efficiency. They work at much higher temperatures and at the same time do not require any lubrication or cooling. Therefore, design changes and substitution of one material for another, are what we may expect on a larger and larger scale. Micro miniaturization has been going on in the electronics industry side-by-side with miniaturization of mechanical products.

The importance of people, of cooperation within multidisciplinary teams, of communication and of the fact that these skills and this knowledge are decisive factors in ensuring the success of the design process and of the product. Balance within the team and in its interaction with the customer is crucial, as well as an emphasis on production, use and consumption. It also clearly demonstrates that designers are decision-makers; that design is nothing but decision-making. Now these decisions have implications and consequences that often go far beyond the simple designer-customer relationship.

Focus on Modern Manufacturing on Product Design

In early eighties, most of the industries were involved in organizing manufacturing operations under control through the use of formal production and materials planning, shop floor scheduling and enterprise resource planning. This has happened with varying degree of success. In the 1990's many industries have attempted to achieve world-class status by implementing total quality management methods. Some of them introduced just-in-time manufacturing techniques

like cellular manufacturing, quick change-over procedure, one piece part flow, kanban, and other techniques resulting in inventory reduction. Spurred by success stories, the industries moved to team-based continuous improvement and experimented with self-directed work teams. Studying best practice used by others and benchmarking them has become a standard procedure.

Agility is the ability to succeed in an environment of constant and unpredictable change. There is trend towards a multiplicity of finished products with short development and production lead times. The impact of this is seen in many companies in the areas of responsiveness, inventory, and organizational structure. An agile approach to manufacturing faces the reality that we must serve customers with small quantities of custom designed parts with perfect quality, 100% on-time delivery, and at very low cost. Companies are forced to organize themselves in such a way that high quality products can be developed very quickly in response to customer requirements.

Focus on Product Teams

The use of cross-functional product development teams has a major effect on both cycle time and quality. With people from different functions working together, development gets done faster because activities can be done in parallel rather than in series. Quality improves because people from different functions work together to understand and solve development problems. The process is quicker and quality is better - so the net result is that it is also cheaper. Team members come from functions such as marketing, design, service, quality, manufacturing engineering, test and purchasing. Often, key suppliers are included in the team. Sometimes, representatives of the customer are also included in the team, allowing the Voice of the Customer to be heard throughout the development process. Team members work together, sharing information and knowledge, and producing better results faster than they would have done if operating in a traditional product development mode. The end result is that products get to market faster, costs are reduced and quality is improved.

Focus on Information

The skills and knowledge of the people within the company become a paramount consideration as a company develops results-based marketing. This knowledge includes product knowledge and experience, but it also includes a rich depth of knowledge of the customer's needs, anxieties, and service requirements. Increasingly, the best way to create close customer awareness is to provide the people within the company, and the customers themselves, a great deal of information. This may be product information, company information, and education and training, product upgrades, manuals, instructions and specification. Orders can be placed automatically from the customer and scheduled within the plant, yielding the customer accurate delivery promises. The design requirements can be automatically picked up in the customer's information systems without drawings or specification being printed and passed. This enables the company to address customer needs with great speed. Design, delivery information, history, accounts receivable, customer service contact can all be integrated. The wide access to the Internet and the World Wide Web opens up a standard and direct method of access information and providing the customers with a standard link into a companies system. The Internet, and other networks, allows

the customer to have a simple and standard link to place orders, make inquiries, send message, and specify their needs.

Focus on Cycle Time

Cycle time has become a key parameter. Reduced lead times open up new market opportunities and improve profits. They reduce market risk by reducing the time between product specification and product delivery. The sooner customers use a product; the sooner their feedback can be incorporated in a new, improved version. In fast-evolving technological environments, products become obsolete sooner. The reduced time between products launch and product retirement erodes sales revenues. Since this phenomenon depends on factors beyond a company's control, the only way it can lengthen a product's life is to get it to the market earlier.

Bringing products to market quickly means that product offerings will be fresher and the latest technology can be included because less time passes between definition of the product and its arrival on the market. The company responds quicker to customers, gets more sales, and sets the pace of innovation. A company, which is good at developing new products, can use this advantage to gain market share.

Focus on Development Process

A clearly defined and well-organized product development process lies at the heart of an effective engineering environment, yet only a few companies have taken advantage of the potential advantages it offers. To make improvements, the process has to be analyzed and understood in detail.

Product development is a complex process involving many poorly understood variables, relationships and abstractions. Converting a concept into a complex multi-technology product under these conditions is not easy. It requires a lot of effort, definition, analysis, investigation of physical processes, verification, trade-offs and other decisions. Companies without a well-defined product development process won't get the benefits they expect from initiatives to improve engineering performance. Without a clearly defined methodology, it's not known which systems and practices are most appropriate - so the necessary integration of an initiative will be difficult to carry out. Any gains that come from use of an initiative in one place are likely to be lost in another place because a coherent solution hasn't been prepared. Companies that understand this and put in place a clear product development process supported by a well-defined development methodology have every chance of becoming market leaders. They can use the methodology as the basis for involving people at all levels and in all functions in defining, designing, and producing the best product and getting it to the market faster.

Focus on Supplier

To respond to the need to get products to market faster, to reduce the cost of developing products and to make sure the product provides customer satisfaction, the product development process

needs to be re-organized. There are many possible approaches to re-organization. Most of them will increase the reliance on suppliers. Companies that focus on upstream product specification and design activities where they can best use their resources will want to outsource downstream activities where they are not cost-effective or are less competent than specialized organizations so suppliers will have a greater role to play in these areas. For many companies, the cost of purchased materials accounts for more than half of their expenses, so it's a good place to try to reduce costs.

Focus on Prototyping

Computer-based simulation and rapid prototyping provide fast and low-cost proof of design concepts. Simulation is carried out to study the performance of a system, product or process before it has been physically built or implemented. Rapid prototyping is the production of a physical prototype directly from a computer-based model of a part or product.

There are material costs savings because all the activities of defining the process for making the prototype and then building it and testing it are no longer needed. Quality is improved because it is possible to define and test many more potential designs using a computer-based model of the part than when using physical prototypes. The benefits of simulation come from use of computer-based models. The benefits of rapid prototyping come from use of physical models produced directly from computer-based models.

Focus on Costing

Activity Based Costing (ABC) is a costing technique used to overcome deficiencies of traditional product costing systems which may calculate inaccurate product costs. The reason for these errors is often that the attributes chosen to characterize costs related to a particular product are attributes of unit products (such as direct labor hours per product) whereas many costs (such as set-up time) are related to batches of products. ABC is based on the principle that it is not the products that generate costs, but the activities that are performed in planning, procuring and producing the products. It is the resources that are necessary to support these activities that result in costs being incurred. ABC calculates product costs by determining the extent to which a product makes use of the activities.

Conclusions

World-class companies to guide the design and development of high-quality products in a step-by-step manner using analytical tools and case studies use the techniques listed in this paper. A typical product design course should include specific topics such as- how to build a product team, characteristics of a self-directed product team, new product creation strategy and process, creative design techniques, principles of design for manufacturing, design for disassembly, optimization, and ergonomics. In view of the recent development in lean manufacturing and information technology, emphasis on value stream mapping and its influence on product

development are important. The paper concludes by summarizing the special topics that need a focused approach to product design.

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APPENDIX shows the tools and techniques linking them to the product development phase.

Concept Development Phase	*Market Studies* *Voice of the Customer* *House of Quality*
Design and Development	*Function Analysis* *Design for Manufacturing* *Design for Disassembly* *Product Modeling using CAD/CAM* *Simulation* *Optimization* *Design for Six-sigma Analysis* *Rapid Prototyping* *Design for Environment & Service*
Analysis and Testing	*Failure Mode Effects Evaluation* *Robust Design* *Statistical Reliability Analysis Tools* *Design for Life-cycle*
Process of Product Creation	*Workplace Design* *Flexible Automation Tools* *Value Stream mapping*

Appendix I Tools and Techniques