2006-2180: IMPLEMENTATION OF PRODUCT REALIZATION CONCEPTS IN DESIGN AND MANUFACTURING COURSES

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Enhancement of Undergraduate Curriculum in Design And Manufacturing Courses Through Implementation of Product Realization

Abstract

The act of revising curricula through a multidisciplinary rapid product realization program is a symbol of UL Lafayette's commitment to undergraduate education in mechanical engineering. As part of its mission." to prepare students for a perfectly consistent transition to industry," an ongoing effort has been undertaken to restructure the undergraduate courses. Traditional design practices have been replaced in the world-class companies by concurrent engineering practices. Hence, it is time to develop an integrated design and manufacturing curricula to strongly enhance the presence of industry on campus.

This paper aims to establish the fact that an innovation in undergraduate course work will have profound implications on students, essentially enabling them to handle real- world problems. In recent years product realization which offers prototyping and fabrication facilities in support of student design activities has attracted much research. Though not first of its kind, the proposed enhancement of undergraduate curriculum is based on the one coherent theme of " Product Realization," technical and professional skills can be coupled to raise students to their full potential. The myriad courses can be bolstered by launching an activity- based "Learning Laboratory", with appropriate infrastructure that allows students to design products from conceptualization to actualization.

Introduction

The accelerating demand for rapid product design and manufacturing, calls for constant technological innovation. The art of launching latest technological concepts and creating better products for future is achieved by strong Engineering judgment. Current research in this area includes lean product development, integration of knowledge and learning into design through product realization and rapid prototyping. In a similar note an initiative is taken to further explore and implement concepts like product realization and concurrent engineering[1] Design and manufacturing tasks are central to mechanical engineering as these experiences begin in the freshman year and last until a real world component is designed and manufactured at a senior level. This process introduces the students to the concept of problems having more than one valid solution and to methods for generating parametric solutions to problems [2]. Thus, a curriculum that provides a base for future professional growth is highlighted and enhanced by launching a " learning laboratory", or "research laboratory", with state- of- the- art rapid prototyping and experimental stress analysis devices [4.]

In order to thrive in a competitive market, corporations must provide new products with superior quality at an acceptable price. Recognizing the high cost involved in developing new products, more corporate efforts have been put into recruiting new and young engineering students who demonstrate the promise and potential to achieve the defined corporate business strategy. A certain level of competence in product design and manufacturing is expected from a student graduating in mechanical engineering [2]. The breadth and diversity of the profession requires an undergraduate curriculum that provides a solid foundation in the basic sciences, including computational skills relating to the use of the latest sophisticated software tools. Toward this end, a path should be laid to apply and to integrate various critical technologies with the conventional technologies. Among the innumerable emerging technologies, Rapid Prototyping through Product Realization is unique in its features. Product Realization in engineering curriculum enables visualizing a solution for the real time experience[1]. Accordingly, current courses can be structured as a project motivated learning phase.

This paper provides a framework to view, interpret and categorize the various approaches to expose freshman-level students to significant design qualities. Key points are that acceleration of innovative ideas and production requires state of the art technologies and closer collaboration between academia, government and the private sector. It requires all engineering disciplines work effectively and achieve excellence in "doing it right for the first time" [3]. The paper describes the necessary steps to implement some of the cross-functional cooperation with schools and industries. Specific examples from ongoing research are cited to point out educational program enhancement, in a broader range of engineering disciplines.

Current undergraduate curriculum ensures a strong foundation in the core mechanical subjects. Definite stress is given to learn the fundamentals of mechanical engineering and engineering problem- solving. Ability to formulate problems and skills critical to the design process are developed. Out-of the-classroom industrial and research engineering experiences are encouraged, so that students cultivate an appreciation for lifelong learning.

1.1 Ongoing Research

There is always noteworthy research and events happening in the implementation of product realization. Considerable research and implementation of product realization at a university level is not a new development. There are many universities such as Stanford University, University of Pittsburg, Penn State University, and University of Washington where programs in product realization are being conducted successfully. Some examples of a similar research are cited here. There is extensive application of product realization at Penn state university where a minor in product realization is introduced in engineering practices and integrated in design and manufacturing. An activity laboratory called an integrated learning factory is greatly expanded in the college of engineering at University of Washington. Much similar to this factory, is the proposed learning laboratory at our university. This kind of experimental learning promotes teaching engineering design using concepts of product realization. Similar implementation is practiced in various other universities, where the existing courses are restructured and new resources like learning factories are added[4].

1.2 Objectives of the Refined Undergraduate Curriculum

The proposed restructuring in the existing curricula aims at effective implementation of product realization concepts into the curriculum and strives, therein, to achieve the following:

- To develop a practice- based undergraduate engineering curriculum that balances analytical and theoretical knowledge with product realization in manufacturing, design, business realities and professional skills;
- To develop a learning laboratory at each partner institution, integrated with the curriculum, to provide facilities for hands-on experience in design, manufacturing and product realization;
- To understand and experience selected elements of the product realization process;
- To develop a complete business plan for the introduction of a new product;
- To bring virtual designs into reality;
- To prepare students for the shift to industry by boosting their confidence, and by strengthening their engineering and soft skills; and
- To develop strong collaboration with industry.

Product Realization

A rapid product development approach is intended to encourage students, from the outset, to consider all elements of the product life cycle, from conception through disposal, including quality, cost, schedule, and user requirements. Based on successful utilization of the opportunities offered by the latest technologies the process aims for the implementation of global design and manufacturing in a global environment [1].

Product Realization Process (PRP) includes determining the customer’s needs, developing specifications, generating conceptual designs, and designing the final product as well as its support processes [1, 6]. This tool improves the design methodology, which is recognized as the single- most essential step in industrial excellence and national competitiveness. Thus integrating industry-sponsored projects into the curriculum through product realization[5]. Integrated Product Realization (IPR) is the concurrent and collaborative process of determining the best solutions at each step in the design and manufacturing process and assuring that the total process is optimized with the best knowledge and tools [9].

An opportunity to understand intellectual property issues associated with new product development is supported by challenging tasks like market analysis, sales, distribution planning, financial reporting and product cost estimation performed. Thus a better involvement in product realization is achieved [4]. The figure 1 below depicts the objectives laid to achieve enhanced curricula through product realization. Each block denotes a specific target to be met.

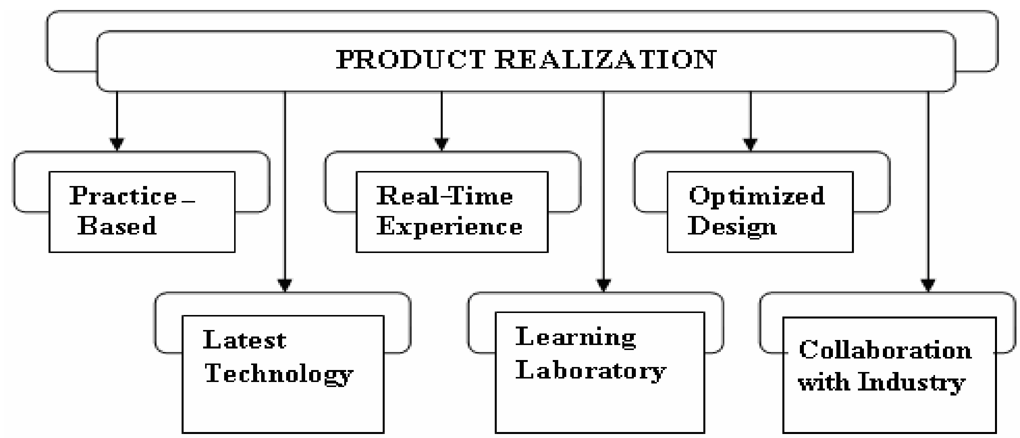

Figure 1: Objectives of the Refined Curriculum though Product Realization

2.1 Product Design and Development Process

The Product development process is the set of activities, starting with the perception of a market opportunity and ending in the production, sale, and delivery of a product. Product realization maximizes the product development capability for a successful product development. The various phases in the development of a project are illustrated in figure 2.

To illustrate the various stages involved in the development of a product, figure 2 begins at the product conceptual state and ends at the product delivery state showing the continuous functional flow through out the whole process [9]. This gives students a basic view of the actual product development process employed at the industries

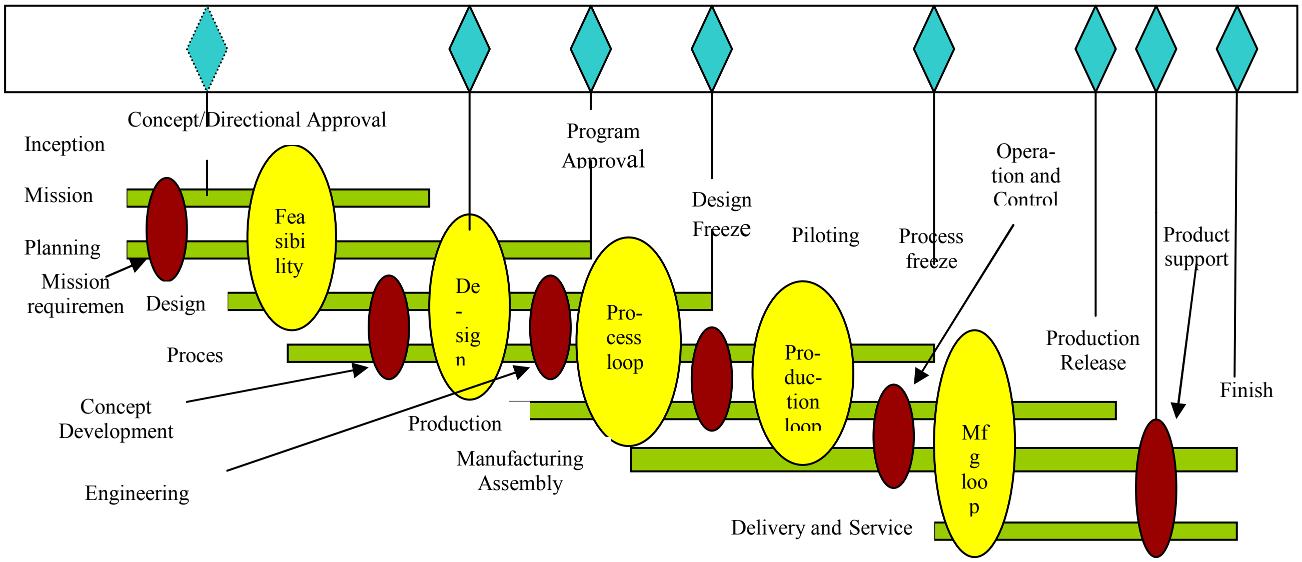

Figure 2. Concurrent Function Development in Product Realization

2.2 Role of Product Realization

The basis to choose "Product Realization" is that it recognizes the necessity to gain product development knowledge in a global context. It can therefore provide students to enhance their skills to produce global products[7, 8]. Thus, a dedicated international educational course is designed .The factors taken into account while designing the courses are, experiences, lessons learned, and the results reached by means of the enthusiastic contribution of students and mentors.

The awareness of the issues related to product realization as a major focus of the academic lectures; the state-of-the-art laboratories provide insight into the supporting methodologies and technologies. The students design activities are offered prototyping and fabrication facilities, and so provide complete turnkey implementation steps from project conception through end-product marketing and sales. Figure 3 presents a picture of the product life cycle.

2.3 Programs in Product Realization

Product realization, with due relevance to product development, has many phases, such as the following:

- Understanding the interaction of design and manufacturing through practical examples;
- Familiarizing oneself with the entrepreneurial skills needed to transfer a new product from an initial idea to market;
- Gathering the technical and management aspects of concurrent engineering and total quality management; and
- Having hands-on experience in designing and manufacturing a product, organizing and managing the effort and interacting with the customer.

2.4 Implementation of the Product Realization Process (PRP)

Ideally, a plan should be an included to elucidate the different phases of the Product Realization Process (PRP).The first phase involves the establishment of needs and generation of ideas, followed by creation of the specifications. Specifications are classified in three categories: functional requirements, design requirements and design criteria [2, 15]. The functional requirements are general in nature and identify "what" the design is required to do [16]. The design requirements specify "how" it is to be done and provide actual quantitative values for some of the constraints. The design criteria address the "guidelines" within which the design must conform. This provides "to what degree" issues such as safety, cost of the system, ergonomics, aesthetics, materials, performance, size, and so on must be satisfied. The study can be initiated by collaborating with a small group of local industries and academic leaders to establish best practices criteria. Then a survey can be offered at various enterprises to identify current Product Realization Process practices. Finally, findings can be integrated in academic surveys, so as to determine potentials and gaps. The different phases of product realization process are presented in a life cycle phase graph in the figure 3.

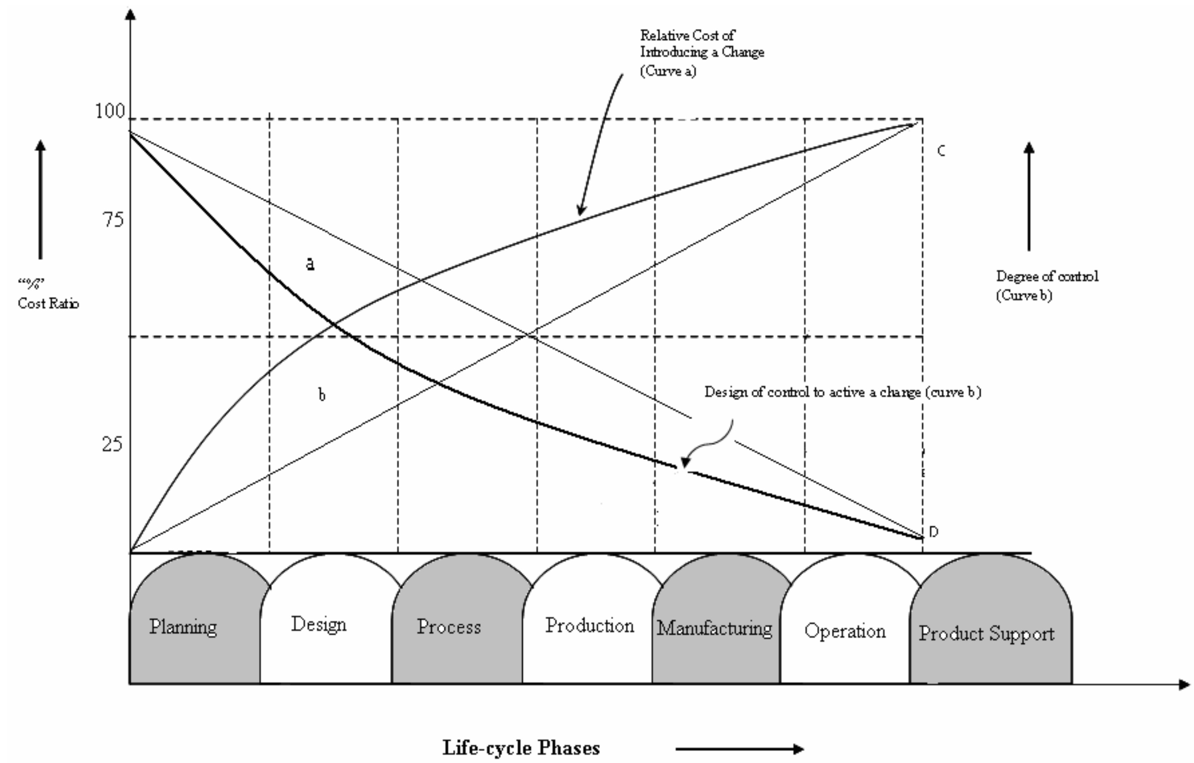

Figure 3. Life- Cycle Phases [19]

Contributions to the Existing Curriculum

3.1. Manufacturing courses:

Some of the design courses offered can be organized so as to instruct an in-depth understanding of the concepts of design for manufacture and assembly (DFMA). By including new DFMA software within existing design courses, the technological and economic feasibility of product manufacture and assembly would be facilitated.

DFMA aims to minimize the number of variants and to facilitate the use of standard parts and features, thereby encouraging the students in the application of the following:

- Generalized technology;
- Common assembly features, joining methods and fasteners;
- Common parts and modules; and
- Currently available 3D systems, 3D printer (rapid prototyping machine). These can be well utilized by including lab hours for working on it and exploring the machine.

The figures below illustrate the various parts of a simple airplane model before and after assembling. The different components are put together using simple lean principles. The application of lean manufacturing techniques reduced the number of components present in the original model.

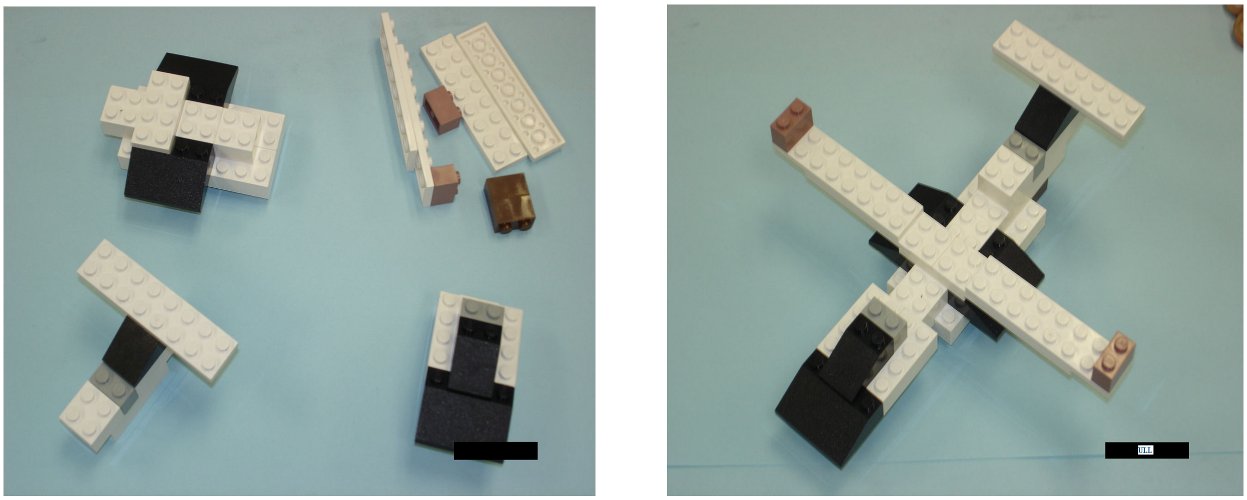

Figure 4. Various components of an airplane model being assembled at ULL

3.1.1 Rapid Prototyping Machine-3D Printer

Courses like MCHE 365, MCHE 463, MCHE 464, which provide an introduction to manufacturing techniques, can be refined further by introducing the concept of design for manufacturing assembly, lean manufacturing and so on [1,3,14].An ability to apply this knowledge can be fostered by real experiments in a research laboratory. A Rapid Prototyping Machine that is a 3D printer is introduced in the design and manufacturing laboratory to help better understanding of the manufacturing principles. Students are expected to design a part or product using their knowledge in CAD coupled with DFMA concepts and a solid prototype of that part can be manufactured using the rapid prototyping device. The figure 5 illustrates the 3D printer when it is actually worked upon. Various components are designed in Pro Engineering software and a stereo-lithographic file is created which is fed to the rapid prototyping machine to give a real part.

The salient features of the current 3D printer are as follows

- Physical models can be printed from 3-D digital data;
- Superior model and prototype quality;
- Highly durable acrylic photopolymer material;
- Easy to use so that no training is needed; and
- Only standard office power is needed.

A picture taken while the undergraduate students were actually working on a 3-D printer is illustrated here in figure 5.

Figure 5. Students working on the 3D Machine

3.2. Courses in Design

The current courses such as Solid Modeling, Numerical Stress Analysis, Thermal Conduction Problems, Dynamic Response of Structures and Engineering Evaluation of Complex Assembled Systems can be modified and enhanced [7, 8]. The courses like MCHE 103, MCHE 263 can be made more sophisticated by introducing new programs such as Product- and Process-oriented Design, Solid Freeform Modeling. The concept of experimental stress analysis or the technique of “photo-elasticity” is being highlighted in the curriculum.

3.3 Photo-elasticity

Photo-elasticity is the study of change of photometric properties of certain solids due to the external load applied to the component under elastic conditions. Photo-elastic stress analysis (PSA) has stood the test of time as one of the most widely applied full field stress analysis techniques. It is a powerful, full-field, non-contact, optical method for determining stresses and load paths in components or structures. It is also widely used for measuring residual stresses in transparent materials, particularly in glass. Innovations in Polariscope design, rapid prototyping modeling and capable user-friendly software are proving to rejuvenate the technology [11, 18]. The very latest advances in modern photo-elastic analysis techniques now offer the opportunity to carry out real-time stress monitoring of components or structures.

This eliminates more time-consuming, complex coating applications, and so suggests wide potential for its future use. With easier-to-apply photo-reflective coatings, it is now a relatively quick and simple task to take a complex part and determine the stress distribution under a variety of loading conditions.

The technique can also be used for determining assembly stresses, due to bolt-up loads or interference fits and the like, and has also found particular use as a quality monitoring tool in the glass industry. This method involves applying a thin epoxy coating to a metal, glass or plastic component or even to a model of a component. When the component is loaded, stresses are transmitted into the coating and when viewed under polarized light, the photo-elastic fringes can be observed and analyzed to determine shear stresses. This method can be used in identifying quickly the load paths within a structure as well as determining areas of stress concentration that could lead to a potential fatigue failure. Hence, this can be an instrumental tool in assisting students in visualizing their design problems. A picture of grey-field Polariscope system is provided here in figure 6 to show the various components in it.

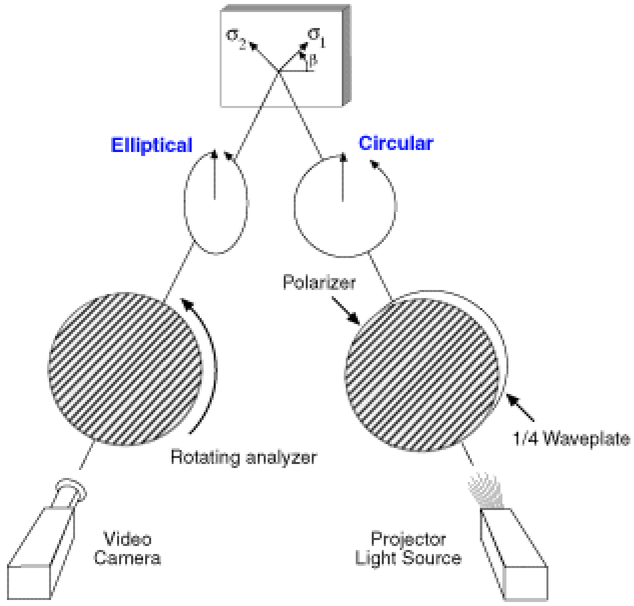

Figure 6.Grey-field Polariscope System Components [10]

3.3.2 Applications of stress photonic system:

Photo-elasticity has a wide range of applications. A few of the many applications are listed below:

- *Component testing*: Load-induced stress, such as spoke of a sports car wheel in cyclic cornering, can be measured easily;
- *Impact testing*: GFP photo-elastic systems can measure dynamic stresses;
- *Flaw detection*: The technology used for flaw detection is quite case-specific. Cracks or disbonds can be detected using thermal methods, while flaws in translucent objects can be detected using a GFP photo-elastic system;
- *Vibrations*: Both DeltaTherm thermo-elastic and GFP photo-elastic systems can measure vibrational stresses- for example the axial vibration of plastic radiator fans for finite element verification;

- *Assembly stress analysis*: The GFP photo-elastic system is ideal for measuring assembly stresses. A thin coating is applied with a special brush when the components are assembled and viewed for stress;

- *Glass Inspection*: Not only can the residual stress state of the finished glass be quantified and checked for defects, but also, by applying a thin coating, any assembly or loading stresses can be detected quickly and easily. This technique can be used for both toughened and laminated automotive glass as well as architectural glass, as well as for bottles, and any other glass product. In addition to glass, the same technique can be applied to most transparent plastics or acrylics, so it is excellent for maintaining the quality of manufacturing processes. For continuous product quality-monitoring, clients could purchase the GFP 2000 real-time automated polar scope, which has the potential to continuously monitor the transparent material production process;

- *Residual stress analysis*: The GFP Photo-elastic Strain Measurement System can measure residual stresses in clear or translucent materials directly with no specimen preparation. Metallic and opaque objects can be handled in the traditional way by coating and then cutting to relieve the residual stresses.

- *Infrared microscopy*: Stress Photonics offers a two-position zoom lens that can be used on cameras with bayonet lens mounts.

- *FEA model verification*

3.4 Concurrent Engineering and Lean Manufacturing

Concurrent engineering is an approach to new product development in which the product and all of its associated processes, such as manufacturing, distribution, and service, are developed in parallel. This concept is supported strongly by design reviews, product development, and design–for-assembly, manufacturing analysis. The basic concepts of this technique can be included in the curriculum, so as to aid students in achieving a better understanding of the real enterprise world [19].

Lean manufacturing is an approach to design and manage production processes that emphasize minimal inventory and just-in-time delivery, as well as to eliminate all wastes and to improve the efficiency of a manufacturing process. A lean enterprise is a set of synergistic and mutually supporting activities. Various building blocks of the lean concept, such as the kanban, standardized work, work balancing, visual management, and total process management concepts, there by ushering them in to the lean world of manufacturing [20].

3.5 Principles of Integrated Process and Product Development (IPPD)

Providing an efficient way to understand the role and interaction of product and process parameters, leads to performance-oriented robust design ad integration. Integrated process and product development is a technique that simultaneously integrates all acquisition activities through the use of multidisciplinary teams, so as to optimize design, manufacturing and supportability processes [19]. The basic principles can be summarized and its objectives presented and taught to undergrad students during academic seminars. Some of the principles can be summarized into the following:

- Better customer relationships,
- Concurrent development of products and processes,
- Early and continuous life-cycle planning,
- Low-risk development and managing project scope, and
- Reengineering the design process.

3.6. Rapid Prototyping

Rapid Prototyping is a technology that produces models and prototype parts from 3-D computer-aided design on the basis of a layered manufacturing technique.

The process creates a real three-dimensional solid model that conveys complete information about the product. The integrated and distributed rapid product realization program being planned emphasizes the importance of "rapid" realization in the new product development with required technology integration and distributed manufacturing. The main innovation of the proposed curriculum enhancement is to introduce the modern enabling technologies of virtual reality solid free-form fabrication.

A course in rapid prototyping and manufacturing would provide a comprehensive, in-depth coverage of solid free-form fabrication and its applications. In this curriculum a course MCHE 578 under special topics is being introduced where in product life cycle design; finding design solutions using optimization technique; The students will gain fundamental knowledge on rapid product realization using rapid prototyping and virtual prototyping techniques, solid free-form fabrication and will learn the trade offs including part accuracy, build speed and material coverage among different fabrication processes. Practical skills such as STL file preparation, part slicing, and support generation can be gained. They will be provided with hands-on experience using commercial rapid prototyping machines. An opportunity to compare solid free-form fabrication with CNC machining in the making of physical parts could be incorporated.

The proposed course consists primarily of three parts:

The first part consists of an in-depth description of solid free-form fabrication processes;

- The second part addresses the fundamentals of solid free-form fabrications
- The third part describes the application of SFF to prototyping, tooling, casting and so on.

Learning Laboratory

The Learning Laboratory, or Multidisciplinary Laboratory, is a new practice-based curriculum and physical facility for product realization whose launch is aimed. It is an activity-based facility with appropriate infrastructure to support the various newly enhanced courses. A new lab replete with rapid prototyping and photo-elastic analyzing equipment would provide a learning environment for mechanical engineering students. It would serve as a meeting space for team discussions, as well as interactive and brain-storming sessions. This lab would serve as an integrating tool for various courses ranging from product design to product manufacturing [5].

Thus, the conceptualization of different stages in a product development can be mastered and transformed into actualization through a team-based product realization process, strengthened by an innovation laboratory like the above-referred learning laboratory.

4.1. Results of Ideal Implementation

The above curricula ensure that, after completion of the proposed schooling, participating students would:

- Understand, as well as get hands-on experience working with the concepts of the product realization process,
- Be able to integrate the elements of conceptual design, geometric modeling, engineering analysis prototype fabrication, production planning and management;
- Get valuable experience in developing their problem-solving skills and have an edge in their future graduate education;
- Learn team spirit, leadership skills, negotiation skills and organizational behavior; and
- Augment entrepreneurial skills needed to transform a novel idea to a real commodity.

4.2 Challenges to Incorporate the Modified Curriculum

A few problems invariably, will be encountered in achieving successful implementation of the refined curriculum. Some of the challenges are as follows:

- Economic feasibility in purchasing the required resources such as the rapid prototyping machine, thermo jet solid object printer, photo-elastic stress analysis system and so on;
- Spreading awareness among the student community about the scope and future avenues open in this field; and
- Getting competent, experienced and dedicated faculty for this relatively new academic horizon.

Conclusion

The enhancement of the curriculum is expected to have significant impact on overall education and infrastructure development, as well as on support of research. Participating faculty and students will broaden their technical horizon in different fields and will gain teaming and other professional skills. Though the planned curriculum is targeted at undergraduate students, the changes also may be of interest to students in master's degree programs in the design and manufacturing engineering. Thus, the curricula provide alternative avenues to develop engineers who are both technically competent and who have significant experience in the design and development of products. Further such programs are motivated by real-time industrial feedback on the performance of these trained graduates.

References

1. Kumbakonam, A and Dwived,.S.N., 2002,"Implementation of Product Realization in Engineering Curriculum for a changing world" presented at 2002 ASEE GSW conference, Lafayette, LA, March 20-22.
2. "Improving Engineering Design- Designing for competitive Advantage", National Research Council, National Academy Press ,Washington,D.C
3. "Innovations in Engineering Design Education", American Society of Mechanical Engineers, A compendium to the ASME Design Education Conference.
4. Lamancusa, J. L, J. Jorgensen, J.Zayas-Castro, "The learning Factory: A new Approach to integrating Design and Manufacturing in Engineering Curricula", Journal of engineering Education, Vol. 86 NO.2 April 2001, pp103-112.
5. Angran Xiao, Janet K. Allen, David Rosen, Farrokh Mistree, "A method To Design Process Architecture In A Distributed Product Realization Environment".

6. Bordogna J.”Next Generation engineering innovation through integration”, NSF technical report 2002.
7. Lamancusa, J. S (1996)., Torres, M., Kumar, V., and J.E. Jorgensen, "Learning Engineering by Product Dissection", Session 2266, Proc. ASEE Annual Conference, June 1996
8. Smith, R. P., Barton, R. R., Novack, C. A., Zayas- Castro, J. L., "Concurrent Engineering: A Partnership Approach", Session 2625, Proc: ASEE Annual Conference, June 1996.
9. http://www.stressphotonics.com/applications.html
10. “Applications of modern automated photo-elasticity to industrial problems”, G Calvert, J Lesniak and M. Honlet.
11. Pine II, B.J., 1993, Mass Customization: The New Frontier in Business Competition, Harvard Business School Press, and Boston.
12. Mitchell M. Tseng and Jianxin Jiao, “Concurrent Engineering for Mass Customization”, in Proceedings of the 41h International Conference on Computer Integrated Manufacturing, Singapore, October, 2000.
13. Marvin Berkowitz, “Product Shape as a Design Innovation Strategy”, Journal of Product Innovation Management, vol. 4.
14. Susan Lachance-Porter, “Impact of user focus groups on the design of new products”, in Proceedings of the 14th National On-line Meeting, Published by Learned Information, Medford, NJ.
15. J.W. Dean Jr. and G.I. Susman. "Organizing for Manufacturable Design", Harvard Business Review. January-February 1999.
16. Howell, S.K., Collier, K., Larson, D., Hatfield, J., Hoyle, G., and G. Thomas. “An Integrated Engineering Design Experience: Freshman to Senior Level”, ASEE.
17. Brian P.Self, Keith Bearden, Matthew Obenchian and Daniel Diaz.” A senior Research Project Applied Across the Curriculum” US Air Force Academy, Colorado.
18. “Concurrent Engineering Fundamentals” by Biren Prasad, Prentice Hall International series in industrial and systems engineering.
19. Computer- aided Manufacturing International Data and an article in Business week, McGraw-Hill Publication, April 30, 1990, p 110.
20. Smith R.P, Barton, R.R, Novack, C.A, Zayas Castro, J.L”Concurrent Engineering: A partnership approach”, ASEE Annual Conference, June 1999.