Cooperative Learning In Design and the Learning Factory

Dale E. Calkins (206) 543-9443 calkins@me.washington.edu
Jens E. Jorgensen (206) 543-5449 jorgen@me.washington.edu
Mechanical Engineering Box 352600 (206) 685-8047 FAX
University of Washington Seattle, WA. USA

ABSTRACT

As part of the Manufacturing Engineering Educational Partnership (MEEP) the University of Washington implemented a Learning Factory (LF) facility as a means of supporting innovative approaches to integrating design and manufacturing engineering education. The facility is an 'activity based' center for the integration of engineering science with 'hands-on' activities and allowing the students to experience cooperative learning by working in teams on industrially sponsored projects. The major emphasis is on design and manufacturing and associated project activities. The facility now supports courses and projects throughout the College of Engineering. The Learning Factory was set up to support courses and activities in design and manufacturing. A faculty and industry committee help define the activities, equipment, and infrastructure that would best serve the courses, student projects, and cooperative learning. The fundamental parts of the LF are:

- *Design Studio*
- *Design Lab*
- *Product Dissection laboratory*
- *Manufacturing Integration Center*
- *Learning Factory Prototype Facility*

In the paper we will discuss the implementation and operation of the center and how it relates to the courses and activities our new Program in Products Realization (PPR). Through this program we have executed numerous industrial projects and successfully participated in national design competitions. Design and production examples from the SAE Formula Car competition and industrial projects related to Mechatronics will be used as cases studies.

1.0) Background

The Manufacturing Engineering Educational Partnership (MEEP)[1] started in 1994 with the major objectives to develop:

1) A practice based engineering curriculum which balances analytical and theoretical knowledge with manufacturing, design, business realties, and professional skills;
2) Learning Factories at each partner institution, integrally coupled to the curriculum, for hands-on experience in design, manufacturing, and product realization;
3) Strong collaboration with industry;
4) Outreach to other academic institutions , government and industry.

Over the past three years the partnership has develop a set of new courses, Figure 1 below, to augment the typical curriculum in Industrial and Mechanical Engineering as well as provide the necessary infrastructure to support hands-on activities in these courses. The course development was also planned to provide students with a continuous exposure to design and manufacturing from the freshman through the senior year. The curriculum contributions by MEEP were the following courses:

[1] The partners are Penn State university, University of Puerto Rico @ Mayaguez, University of Washington and Sandia National Laboratories.

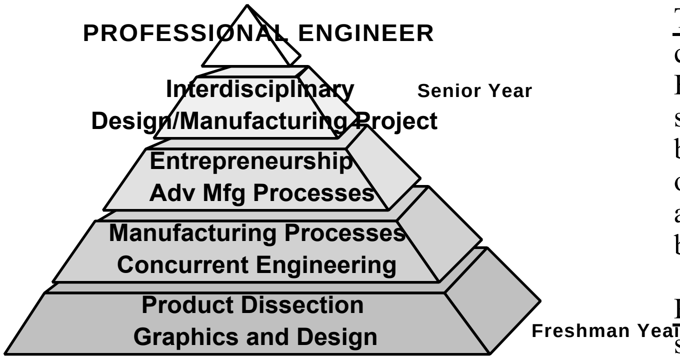

Figure 1 MEEP Curriculum Program Development

Product Dissection[2] : Here students examine the way in which products and machines work: their physical operation, the manner in which they are constructed, and the design and societal considerations that determine the difference between success and failure in the marketplace. Students, working in interdisciplinary teams, will dissect several common products to discover their internal functions and to critique their design, manufacturing methods, materials selection and disposability.

Concurrent Engineering: [3] In this course we present the origin and meaning of the term *concurrent engineering* and discusses its role in modern engineering companies. The effect of concurrent engineering practices on other product life cycle issues such as safety, reliability, maintainability and product disposal are examined. Additionally, case studies from various industries are presented and speakers from local industries present a practical perspective.

Technology Based Entrepreneurship: This course, developed in conduction with the Business School, focuses on the process of starting, financing and managing a new business. It also focuses on the management of existing enterprises and includes such topics as risk, product/markets, objectives and goals, business plans, control, staffing and financing.

Process Quality Engineering: Exposes students to the importance of statistical and probabilistic methods in the current TQM culture. Students learn to apply probability models and statistical tools to engineering problems. The course provides a laboratory experience, where students design their own experiments, collect data, and apply appropriate statistical analysis tools to that data.

Interdisciplinary Capstone Design: The capstone course provides students with the opportunity to practice the design of products, processes and enterprises from conceptualization to actualization. Students collaborate with partners at other MEEP schools and work in interdisciplinary teams on open-ended hardware-oriented projects provided by industry. The project activity ideally spans a full academic year.

2.0) Strategy for the Integrated Learning Factory (ILF)

In order to support the new curriculum development each school developed an Integrated Learning Factory, Lamancusa, et. al. [3], Lamancusa, et. al. [4], Lamancusa, et. al. [5], DeMeter, et. al. [6], Lamancusa, et. al. [7] and Calkins, et. al. [8]. The Integrated Learning Factory is an activity based facility with the appropriate infrastructure to allow students to experience the hands-on activities of product dissection and benchmarking, Jorgensen, et. al. [9], carry out conceptual and detailed design and analysis; provide appropriate meeting space for team discussions; and finally a facility for products prototyping and performance testing.

2.1) ILF Description

[2] Lamancusa, John S., Torres, M., Kumar, V., and J. E. Jorgensen, "Learning Engineering by Product Dissection", Session 2266, Proc. ASEE Annual Conference, June 1996

[3] Smith, R. P., Barton, R., Novack, C. A., Zayas-Castro, J. L., "Concurrent Engineering: A Partnership Approach", Session 2625, Proc: ASEE Annual Conference, June 1996

The Integrated Learning Factory at the University of Washington is now operating in its second year. As a new instructional laboratory of the College of Engineering, it simulates a design and manufacturing workplace and supports the new interdisciplinary Product Realization minor, which encourages a hands-on approach to integrating design, manufacturing and business. The Integrated Learning Factory is a new approach to design and manufacturing engineering education. It combines curriculum revitalization with coordinated opportunities for application and hands-on experience.

This "activity based" approach erases the traditional boundaries between lecture and practice, classroom and laboratory, academia and industrial practice. The Integrated Learning Factory (ILF) at the University of Washington covers approximately 5,500 ft.^{2} The ILF includes the following components:

- Design Studio
- Design Lab
- Product Dissection Lab
- Manufacturing Integration Center
- Factory Prototype Facility (Five work cells)

Design Studio

The Design Studio is for use by students for design collaboration. Included are a floor-to-ceiling cork working wall for use in brainstorming exercises, an overhead computer and video projector, a "Smart Board" projection screen and two whiteboards. ILF Coordinator Mike Safoutin is shown in Figure 2 demonstrating the touch-sensitive Smart Board projection system. Distance conferencing software also allows for student/client collaboration.

Design Lab

The Design Lab, Figure 3, consists of fourteen HP Vectra PC workstation hosting a variety of software for use in the design, manufacturing, and report production process. Output capability includes a laser printer, plotter, and a 3-D rapid prototyper. The Design Lab provides computer workstations to support student team design collaboration as well as in-class teaching.

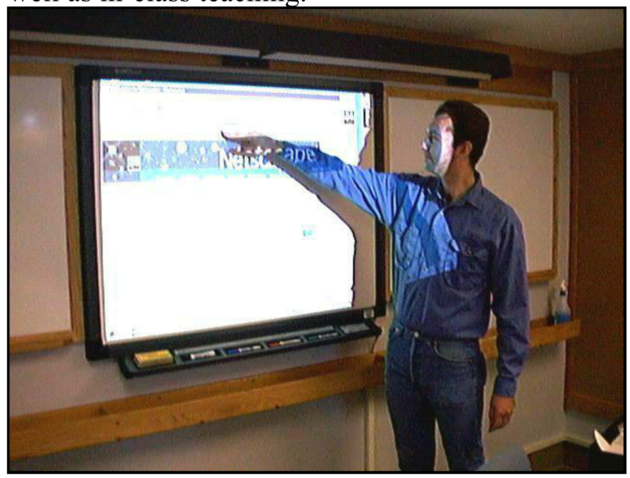

Figure 2 :Design Studio touch-sensitive Smart Board projection system

Figure 3 : The Design Lab supports student team design collaboration

Product Dissection Lab

The Product Dissection Lab area, Figure 4, was designed to support dissection activities of eight groups of four students at a time. There are eight workbenches, each equipped with a set of common tools. Certain special tools are also available. We have added computer terminals to allow students access learning material on dissection, carry out calculations and write reports.

Figure 4: The Product Dissection Lab provides bench space, tool sets, and project storage space for up to eight student teams.

Manufacturing Systems Integration Lab

The Manufacturing Integration Center, Figure 7, provides hands-on opportunities for students to utilize the concepts and principles of integrated manufacturing, that is, the efficient transformation of customer requirements into product designs, and the coordination of product information, materials, and production processes to satisfy those customer needs.

Factory Prototype Facilities and Work Cellss

The Robotics Assembly work cell houses a Seiko industrial robot donated by Hewlett-Packard. The robot is interfaced with a PC controller. The robot was originally designed to assemble small parts on HP printers. For a student design project, the robot is being reprogrammed to play checkers, using as game pieces the same parts it was designed to manipulate in the factory.

The Self-Piercing Riveter work cell contains a state-of-the-art HENROB self-piercing riveter. Metal pieces are riveted together without the need for a pre-drilled hole, much as a stapler staples paper. In industry, this technique takes the place of spot welding. The riveter has been used in the SAE Formula Car design competition to construct portions of the vehicle frame. The CNC Lathe and CNC Milling work cells will house CNC horizontal and vertical milling equipment for creating prototype parts in metal and plastic. The Injection Molding cell contains an injection-molding machine and facilities for moldmaking and duplicating prototype parts in plastic and resin. This cell is often used to create durable copies of the fragile 3-D models output by the rapid prototyper in the Design Lab.

Student Team Study Area

The Student Team Study Area, Figure 5, include a series of conference tables that can the student team can use on an "as needed" basis to meet and work. The area also includes a display wall to highlight student team work. The posters are removable so that they are easily changed as the school year progresses. This wall facilitates an understanding of student learning to ILF visitors.

Figure 5: A Display Wall is dedicated to student project exhibits.

3.0) The Undergraduate Products and Processes Realization Program

As a result of the MEEP development activities, each school recognized the need for a more formal program in Product Design and by the Fall of 1996 each school had obtained an approval for an Option or a Certificate Program in Product Realization (PPR). These programs must meet individual university and departmental requirements as well as providing core and option courses in PPR and is indicated schematically in Figure 6.

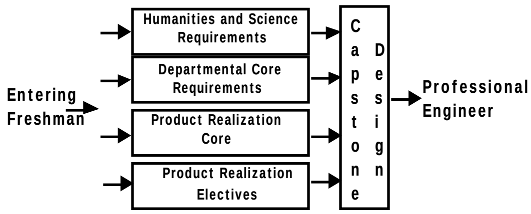

Figure 16 : Elements of the Product Realization Program (PPR)

The program intends to capture the incoming freshman with an "introduction to design" course and to build on this exposure by providing at least one course each semester (or quarter) in residence related to design, manufacturing, business and operational issues. Implementation at each school is carefully tailored by weaving of existing departmental core and university requirements with core and options courses in the PPR option.

Benchmarking in Teaching Design

Benchmarking is a business management tool that has been employed for many years to search for ‘best practices’ in, for example, business operations, customer relations, product design and manufacturing. To our knowledge, its application to the process of teaching design in a university setting is novel. As part of the Manufacturing Engineering Education Partnership (MEEP) we have attempted to restructure how we teach design to emulate an industrial setting and to provide more ‘hands on’ experience for the students.

Our implementation of benchmarking relies on product dissection to enable students to establish a database for analysis of the product design in terms of its function, performance, and manufacture. We have introduced the concept in our Junior level course, Introduction to Design, as a means for the students to experience working on real commercial products. Examples of such products are the electric drill, the hand held mixer, the food blender, and the oscillating cooling fan. The selection of the product and its complexity, or simplicity, in design and manufacture is less important in comparison to the process the students have to perform in order to arrive at the desired results and conclusions. The process we have employed, the resource requirements, and the educational benefits we have observed from using this process over the last two academic years are described.

Product Dissection

Product dissection and benchmarking are processes commonly employed in industry to improve product design, produce superior performance and product quality. The process, when applied in an undergraduate academic setting, can improve the process of teaching design. It has been applied to teach undergraduate mechanical engineering students at the Junior level. The students, working in teams,. conducted a market study of hand held kitchen mixers, selected an appropriate sample of product units and carried out the benchmarking study by dissecting each unit. A design data base, with customer expectations as the reference variable was assembled and the '*best in class'* established for both a single product and each customer expectation. A re-design exercises was carried out on a 'mid-performing' product units to bring them to '*best in class'* or exceed it.

The Design Process and Product Dissection

The design process is the procedure whereby the designer, starting with customer or market expectations, develops a product or a process to meet a specific demand. To describe this process , as shown in figure 1, current textbooks focus primarily on the creation of design concepts [4], the development and analysis of detailed designs [5], material selection and, somewhat less rigorously, on the manufacturing and testing of the finished product.

The practical, but equally important issues of product specification, analysis of critical design features, historical and/or current test data and the creation of a data base for the design process are still alien to the students.

In dissecting any given product we examine how the device works, the relationship between the parts and components and the functional and operational requirements of the product. Critical design features and the detailed implementation of the design concept to meet the product specifications can be observed and cataloged. Furthermore, the manufacturing and assembly processes employed can be inferred. Therefore, we can compliment current text books by appropriately 'closing the loop' on the design process and assemble a design knowledge data base about the product.

The Benchmarking Process

In industry, benchmarking is an accepted technique used to identify the strengths and weaknesses of a wide range of processes, procedures, and operations associated with the company business. Areas of concern ranges from customer satisfaction, product design and manufacturing, and business operations such as order entry, billing, or repair services. Benchmarking [6] typically searches for the best practices, thus leading to superior performance. The typical steps in the process are shown in figure 2.

Benchmarking in a University Setting

Purpose and Objective: The purpose is to emulate industry's product design process by having students, working in teams, examine, test, and re-design an industrial product to meet market demand for product superiority. The educational objective is to provide a natural setting for implementation of the design process that they will experience in industry.

Working on a real product allows the student team to discover and confront issues that the original product designers had to confront, thus instilling knowledge and experience not provided through text books.

Student Background: Prior to starting the benchmarking activities the students had completed a simple design exercise (a bird feeder), a product dissection (electric drills), and been exposed to industrial design, design for manufacturing and assembly, economic analysis, patents, and project planning. These topics were discussed in lectures, and exercises led by faculty and engineers from industry participating in our program.

Context-Based Capstone Design Project

An architecture for a context-based capstone design course based on the Society of Automotive Engineers (SAE) Formula Car competition, Calkins [10] and [11]. "Formula SAE" is an intercollegiate engineering competition in which engineering students are to conceive, design, build, test and race a Formula Style car. The competition is based on the concept of a hypothetical manufacturing firm that has engaged a student design team to produce a prototype car for evaluation for production at a cost of $9,000 for a production run of 1000. The class is a structured Design /Build team concept for offering students an introduction to and an experience in an environment which is based on systems design technologies. The students must not only fulfill the technical engineering duties required in the design of the car, they must also participate in the business administration functions such as fundraising, financial control, records keeping, documentation and inventory control. The nine month long project concept allows not only the design, but also the fabrication and testing of the design.

In addition to ME 495, two quarters of ME 499 "Special Projects" are also taken so that the project team will begin in the Fall quarter and be continuous through the Spring quarter to the competition. The cars are designed, built and tested during the three quarter school year, over a period of about seven and one-half months. The competition occurs in mid-May which is about one month before the end of the Spring quarter. The overall goal for the class is to give the students an experience in systems engineering and to be a true learning by doing experience. This includes making sure that the project experience is one that truly reflects the engineering design process, rather then being just a weekend garage mechanic exercise. This class is the environment where the student will integrate all of the other individual experiences that they have had in taking the engineering science courses. Not only must they have skills in using these tools, they must learn to work together as team on a "system".

Concepts such as part and sub-system ownership, Design to Cost and Concurrent Engineering are embedded in the course structure as the students work in technology based "Design/Build" teams. To help in the design process, the students rely on the use of the Computer-Aided-Design and Engineering tools available in the ILF Design Lab. SDRC, an ILF sponsor has donated the CAD/CAE program "I-DEAS" which is being used to design the 1998 entry, which is an evolution of the 1997 car shown in **Figure 7.**

Knowledge-Based Engineering Graduate Design Course

Based on Knowledge Based Engineering (KBE) and its applications in design engineering is rapidly being embraced as the next step beyond CAD. This emerging technology is a programming tool used to develop a virtual prototype for the design of an established product in a given design domain. Existing knowledge about a class of designs is utilized and organized into a database format usable by computers. The product model which is developed in the KBE environment is a virtual prototype. A virtual prototype has all of the geometric characteristics or attributes of the product as well as the non-geometric attributes such as materials, mass properties, stress and deflection characteristics, etc. Once the "virtual prototype" is created, it can be used by the designers to evaluate the success or merit of the design configuration, and then modify it if desired. The product model represents the engineering intent behind a geometric design. The information contained in a product model includes physical attributes like geometry, material type and functional constraints.

Figure 7: UW 1997 SAE Formula Car

The Department of Mechanical Engineering at the University of Washington has recognized the importance of KBE in engineering, and a graduate level design class has been developed and offered. The class, "ME 570 - Knowledge-Based Engineering (KBE):Design Methodology," Calkins, et. al. [12], covers both the emerging technology of KBE and its application by having the students go through the process of developing a product model. Using heuristically developed design rules, it covers tool development for components, assemblies and systems. A KBE system stores knowledge about a system in a product model composed of engineering rules, which are both geometric and non-geometric, and describes how the product is designed, analyzed and manufactured. One product that is being used as the basis for a generic virtual prototype is the hand held battery powered vac. The students first map the product through the development of a decomposition tree, Figure 8 and then model the parts using parametric geometry, Figure 9.

Conclusions

Under the Manufacturing Engineering Educational Partnership (MEEP), the University of Washington implemented a Learning Factory (LF) facility as a means of supporting innovative approaches to integrating design and manufacturing engineering education and has implemented a new design and manufacturing “Program in Products Realization (PPR)”. Through this program we have executed numerous industrial projects and successfully participated in international design competitions such as the SAE Formula Car competition. The introduction of Knowledge-Based Engineering)KBE) has also been accomplished at the graduate level.

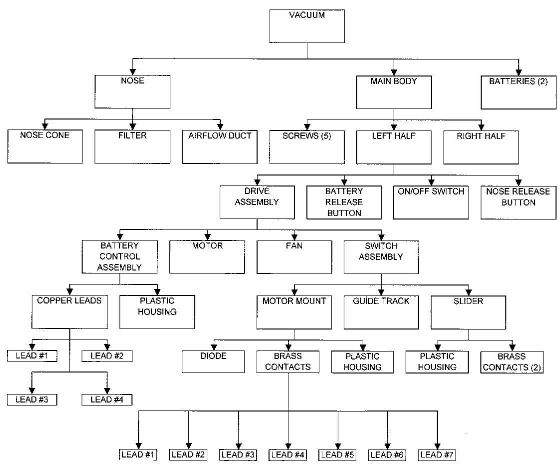

Figure 8: Hand Vac Product Decomposition

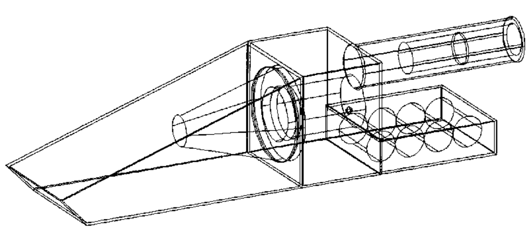

Figure 9: Hand Vac Parametric Geometry

REFERENCES:

[1] Lamancusa, J., Torres, M., Kumar, V., and Jorgensen, J., “Learning Engineering by Product Dissection,” *1996 ASEE Annual Meeting Proceedings*, ASEE Washington, D.C., 1996.

[2] Smith, R., Barton, R., Novack, C., and Zayas-Castro, J., “Concurrent Engineering ; A Partnership Approach,” ASEE Annual Conference, June 1996, Session 2625.

[3] Lamancusa, J., Jorgensen, J. and Zayas-Castro, J. “The learning factory : A New Approach to Integrating Design and manufacturing into Engineering Curricula,’ ASEE Annual Conference, June 1995.

[4] Lamancusa, J., Jorgensen, J. and Zayas-Castro, J. “Putting Design and Manufacturing back into the Engineering Curriculum,’ ABET Annual meeting, San Diego, CA, October 1996.

[5] Lamancusa, J., Jorgensen, J., Zayas-Castro, J. and Ratner, J.. “THE LEARNING FACTORY - A New Approach to Integrating Design and Manufacturing into Engineering Curricula,” Proceedings, ASEE Annual Conference, Anaheim, CA, June 1995, pp. 2262 - 2270.

[6] DeMeter, E., Jorgensen, J., and Rullan, A., “The Learning Factory of the Manufacturing Engineering Educational Program,” *Proceedings of the International Conference on Manufacturing Education*, SME, San Diego, CA, March 1996.

[7] Lamancusa, J., Jorgensen, J., and Zayas-Castro, J., “The Learning Factory-An Approach to Integrating Design and Manufacturing into the Engineering Curriculum,” *ASEE Journal of Engineering Education*, April 1997, pp. 103-112.

[8] Calkins, D., Jorgensen. J., Safoutin, M., Heim, J., “The Integrated Learning Factory: An Educational Paradigm’s First Year of Operation,” ASEE Annual Conference, June 1998, Seattle, WA., Session 3666.

[9] Jorgensen, J. E., Fridley, J. L., and Lamancusa. J. S., "Product Dissection: A Tool for Benchmarking in the Process of Teaching Design", Proc: Frontiers in

Education Conference, Salt Lake City, UT, November, 1996

[10] Calkins, D., "Focus-Based Design Education: A Case Study," *ASME Resource Guide to Innovation in Engineering Design Education*, ASME 1993 Design Education Conference, Orlando, FL, 24-26 March 1993, pp. 109-112.

[11] Calkins, D., "SAE Formula Car Competition: A Study in 'Systems Engineering'," *1992 ASEE Annual Conference Proceedings*, Toledo, OH, 21-25 June 1992, pp. 816-823.

[12] Calkins, D., Egging, N., Scholz, C., "A Knowledge-Based Engineering (KBE) Graduate Design Class," ASME International Conference on Design Theory and Methodology Design Education, September 1998, Atlanta, GA.