

Draft

AN EDUCATIONAL PROGRAM IN PRODUCT REALIZATION

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ABSTRACT

As part of the Manufacturing Engineering Educational Partnership (MEEP), design and manufacturing courses have been restructured into a sequence leading to a program in Products and Processes Realization for our undergraduate students. The purpose is to provide a broad based, interdisciplinary program for undergraduate students interested in the design and manufacturing of industrial products.

Each school has taken a different specific approach to the implementation of the program but the essential features of the program is that students experience design and manufacturing activities each semester (or quarter) in residence. The program bridges the gap between engineering science and practice, and allows students to work in teams on real industrial problems.

The implementation of the program has required restructuring of existing courses and the addition of new resources, such as the creation of Learning Factories at each of the institutions. The Learning Factories provide modern facilities for design, manufacturing, fabrication and testing of products and processes. The paper describes the new degree programs at each of the institutions, the resources required, and operational experiences to date.

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I 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 realities, 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, see 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:

Product Dissection² : 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.

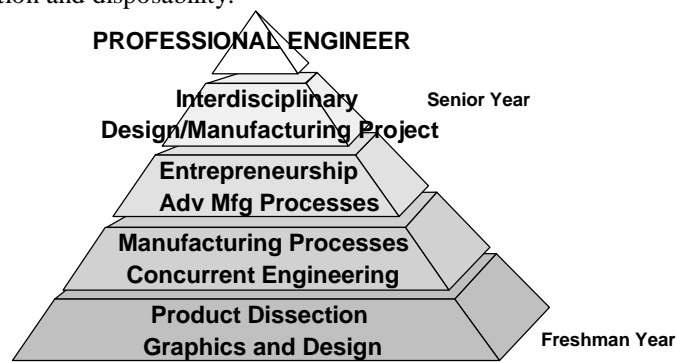


Figure 1 MEEP Curriculum Program Development

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

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

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

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.

In order to support the new curriculum development each school developed a Learning Factory^{4,5}. The Learning Factory is an activity based facility with the appropriate infrastructure to allow students to experience the hands-on activities of product dissection and benchmarking⁶; 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.

II The 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 2.

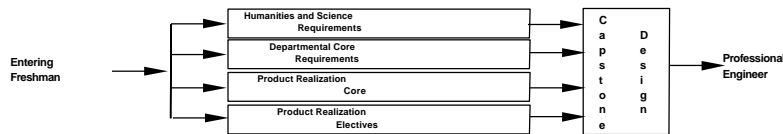


Figure 2 Elements of the Product Realization Program (PPR)

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.

III Implementation at Partner Institutions

Penn State University:

At Penn State a 21-credit interdisciplinary minor is designed for students in all engineering disciplines who are interested in engineering practice in integrated design and manufacturing. The program culminates with a one- or two-semester project involving the design and manufacture of a new product. The purpose of the minor is to offer students state-of-the-art practice in integrated product/process design and manufacturing. Students

⁴ Lamancusa, J. S., Jorgensen, J. E., and Zayas-Castro, J. L., "The Learning Factory: A New approach to integrating design and manufacturing into engineering curricula" Proc: ASEE Annual Meeting, June 1995. Paper to Appear in the J. of Engr. Education, April, 1997.

⁵ Lamancusa, J. S., Jorgensen, J. E., and Zayas-Castro, J. L., "Putting design and manufacturing back into the engineering curriculum" Proc: ABET Annual Meeting, San Diego, CA, October, 1996

⁶ 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

completing the minor should: 1) understand the interaction of design and manufacturing through practical examples, 2) be familiar with the entrepreneurial skills needed to transfer a new product from initial idea to market, 3) understand the technical and management aspects of concurrent engineering and total quality management, and 4) have hands-on experience in designing and manufacturing a product, organizing and managing the effort, and interacting with the customer.

The Product Realization Minor offers students in traditional engineering disciplines an alternative path to a degree which directly prepares them for careers in manufacturing, design and product realization. Students who choose this program begin working in the Learning Factory (a new hands-on interdisciplinary laboratory for integrated manufacturing and design) in the first year as a direct component of their course work. This multi-disciplinary, hands-on experience continues and expands in scope each year to compliment the academic programs in individual departments. Throughout, students will experience the total process of product realization to meet customer needs: from conceptual design through prototyping, marketing, business planning, production, total quality improvement and ultimate disposal.

The course work for fulfillment of the Product Realization Minor involves design, manufacturing and business realities for engineers. As illustrated in Figure 3, Engineering Design and Graphics (EDG 100) and Engineering Physics (PHYS 201) are prerequisites and provide the fundamental knowledge for the minor in the freshman year. This is followed by Product Dissection (ME 288) and courses in Manufacturing Processes which provide the base engineering knowledge. The course incorporates both lecture and laboratory.

Six credits in laboratory oriented Manufacturing Processes are also required. Different courses are required based on one's major. An Industrial Engineer typically takes 12 credits in manufacturing processes, production engineering and manufacturing systems while a Mechanical Engineer typically takes a course in manufacturing processes and can elect to take a follow-up elective in production engineering, advanced materials processing or microprocessor control of manufacturing processes. Students in other engineering majors are allowed the latitude to select laboratory oriented manufacturing process courses which are relevant to their field of study.

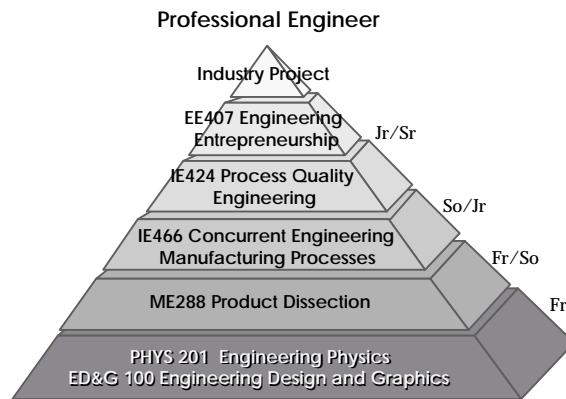


Figure 3. Structure of the Product Realization Minor at Penn State

Beyond this preparation in design and manufacturing all students take courses in Quality Engineering (IE 423 or IE 424), Concurrent Engineering (IE 466) and Engineering Entrepreneurship (EE 407). The Quality Engineering requirement is met by a course in quality control for Industrial Engineers (IE 423) or a new course in applications of statistics to obtain quality (IE 424) for all others. The new course combines elements of probability, tests of hypotheses, regression, design of experiments and control charting along with a an innovative laboratory. The Concurrent Engineering Course (IE 466) investigates engineering and management tools for concurrent product and manufacturing process development. The course makes heavy use of case studies. The Engineering Entrepreneurship course (EE 407) covers the practical aspects of the startup of a business, with elements of finance, marketing, management, the basics of product manufacturing, and an overview of activities in new product prototyping.

The final requirement of the minor is to take a one or two semester capstone design experience. Industry sponsored projects frequently requiring interdisciplinary teams of students are used to develop open-ended

learning experiences for students where they must interface with a customer while performing product/process design. The capstone design project has different course numbers in each department. Students sign up for projects and are enrolled in the capstone course of the faculty member supervising the project regardless of department affiliation.

University of Puerto Rico at Mayaguez (UPRM):

Currently, there are five disciplines participating in this effort at UPRM: Industrial, Mechanical, Electrical and Chemical Engineering and Business Administration. There is a Certificate in Manufacturing for each engineering discipline which basically consists of four to five courses.

Students are required to take the following MEEP courses as a core: Product Dissection, Technology Based Entrepreneurship and Concurrent Engineering. Product Dissection is coordinated and offered by Mechanical Engineering, Technology Based Entrepreneurship is coordinated and offered by the College of Business, and Concurrent Engineering is coordinated and offered by the Department of Industrial Engineering. Typically about 75-80 students are enrolled in these three courses. In Technology Based, Entrepreneurship students develop innovative ideas of a potential marketable product. This has been conducted in coordination with Penn State and the University of Washington. At UPRM these potential products are given to the students in Concurrent Engineering to apply the design methodology, redesign and refine products, develop prototypes and demonstrate the manufacturing and business potential. The entrepreneurial spirit that has been developed is of major relevance to the economy of Puerto Rico. It is important to highlight that these three members participate in lecturing and about eight faculty members do the same in Entrepreneurship. More than 20 faculty members currently participate in the MEEP effort. This participation ranges from technical advice on projects to coordination and course delivery.

To complete the requirements for the Certificate, students take other courses related to manufacturing aspects of major interest to them and to industry as well as the courses already required in their departmental curriculum. For example, IE students may take courses in manufacturing simulation, robotics and automation or product design. Electrical, Chemical and Mechanical Engineering majors may take some of those courses plus courses that are required for Industrial Engineering majors, but are electives for them. Examples of these are applied statistics, quality control, manufacturing process, and plastics engineering.

University of Washington (UW):

The Products and Processes realization program will consist of a set of core design and manufacturing related courses (24 quarter credits) plus technical electives (16 quarter credits) that will complete the 'option'. The core program is shown in figure 4. In this core the entering student will initially progress through a series of 'skill' related courses. The freshman year will start with Engineering 100 Introduction to Engineering Design.

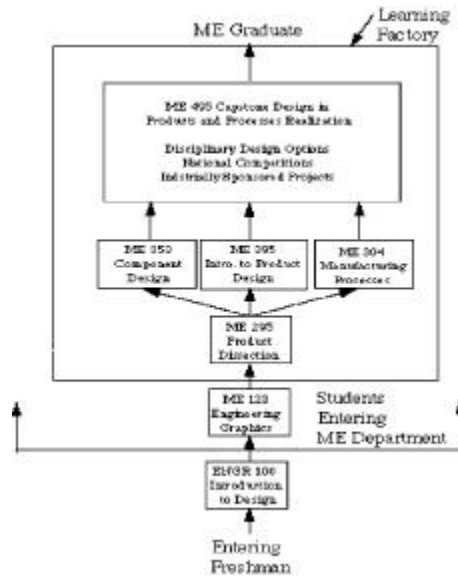


Figure 4 The Product and Processes Realization Core in ME

Upon entry into a departmental program (the example here shows Mechanical Engineering), typically in the Sophomore year, she/he will progress throughout the sequence of ME 123 Engineering Graphics to learn how to communicate their design ideas graphically through sketches and CAD, and further enhance their design activities in ME/IE 295 Product Dissection.

The Junior year is devoted to integration of design and manufacturing knowledge. ME 304 Manufacturing Process gives the students the basics of manufacturing principles and material selection with hands on experience in the various processes. In ME 395 Introduction to (Product) Design, we extend the idea of product dissection with the introduction of Product Benchmarking as a means to teach product and process design. ME 352 Mechanical Systems Design is devoted to the details of system component design. In all these courses we envision a vigorous interplay between classroom lectures, design analysis, and hardware implementation or demonstrations (dissections) in the Learning Factory.

The senior year is devoted to specialization through a series of technical threads each with a capstone design effort:

The Mechatronics Thread: The Mechatronics thread is a sequence of option courses to be taken in the senior year. As shown in the figure 5, four of these courses will be required for each of the students enrolled in the program: Automatic Control (ME 471) and Instrumentation (ME 473) are to be taken in the Autumn Quarter; Embedded Computing (ME 477) is to be taken in the Winter Quarter; and the program ends in the Spring Quarter with Mechatronics Capstone Design (ME 495). In addition to these required courses, students in the Mechatronics thread will take at least two Mechatronics-related technical electives. Suggested technical electives are: Advanced Dynamics (ME 469), Vibrations (ME 470), Advanced System Modeling (ME 474), Electronic Design Lab I (Phys 334) and Electronic Design Lab II (Phys 335).

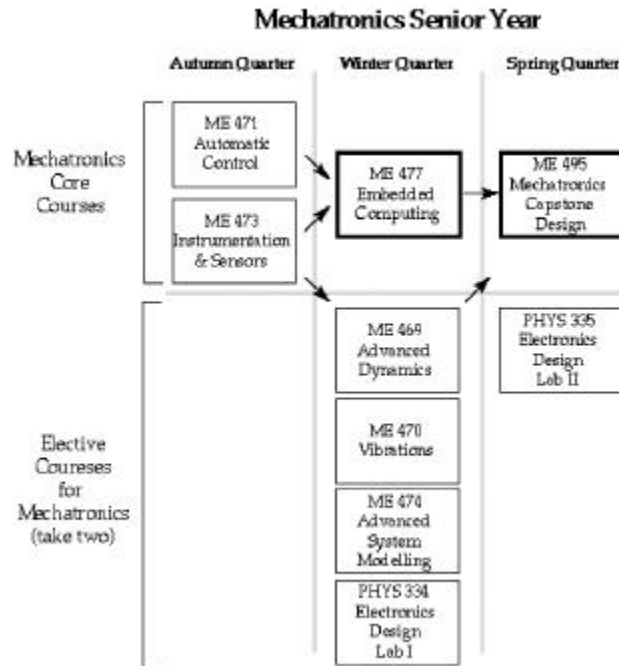


Figure 5 Mechatronics Option

The courses in the Mechatronics thread exist in our present curriculum and will not need to be developed with the following two exceptions: Embedded Computing (ME 477), which was recently upgraded with new laboratory equipment; and Mechatronics Capstone Design (ME 495), This latter course will be offered for the first time in the Spring Quarter of 1997.

The Products and Processes Thread: This thread will consist of the PPR core given above plus technical electives. It is expected that students will take ME 495 Capstone Design plus and additional ME 499 Independent Study to provide a two to three quarter sequence of Industrial Projects design in their Senior Year. In addition they will be able to select 8 to 12 credits of technical electives. These could be ME 478 Finite Element Analysis, ME 480 Computer Aided Design and Technology, ME 409 Numerical Control and Computer-Aided Manufacturing, ME 485 Electronic Packaging and Materials, IE 392 Concurrent Engineering, IE 494 Design in Manufacturing Firms, or IE 496 Technology Base Entrepreneurship.

The Design Competition Thread: Students in this thread are involved in National Competitions such as the SAE Formula Car, Human Powered Submarine, The Raven Project (Human Powered Airplane) etc. Students are typically required to sign up for three quarters of design (ME 495 plus two quarters of ME 499). Additional technical electives can be chosen as in the PPR option above.

IV Results to date

All partners schools have incorporated the MEEP developed courses in their programs and the Learning Factories have become the central focus for these programs. These accomplishments have been possible to a major extent, because of the existence of this partnership. The visibility obtained plus the opportunities provided to students, faculty and industrial sponsors has allowed us to develop a more comprehensive approach of enhancing the educational process. Moreover, it has permitted every participant to become exposed to a more interdisciplinary environment, that is not only applicable to manufacturing, but to the learning/teaching process as a whole. This by itself constitutes a significant change in the culture and has helped to institutionalize our efforts.

Penn State University

The Minor was just recently approved at Penn State. Based on the initial reaction and interest it will have wide appeal. Students from five engineering disciplines have inquired and approximately 15 are now formally in the program, primarily in Industrial and Mechanical Engineering. It is anticipated that in the steady state, 30 students per year will graduate with this degree option. Other departments will need to take formal action to recognize

courses of the minor as electives or replacements for requirements. These discussions will take place over the coming months to widen participation. In Industrial and Mechanical Engineering the minor can be earned by taking only three additional credits with appropriate electives and substitutions. Discussions with other departments will hopefully lead to similar situations where their students can obtain the minor as easily.

The Product Realization Minor and Learning Factory have gained significant administrative support at Penn State. The College of Engineering and some departments have combined to fund a technician for the Learning Factory while the University has funded a joint IE/ME faculty position to teach Product Realization courses.

University of Puerto Rico @ Mayaguez:

Currently about 85 students are in these paths, and the interest is growing rapidly. The core "MEEP courses" are offered every semester, although this may change. For the most part students are involve in Capstone Projects that are practice-based, performed in industrial settings, teamwork oriented and heavily emphasize the use of written and oral communication skills. About 85 projects are administered each semester and this is in a growing mode, since Chemical and Electrical Engineering are expanding their efforts in this regard. These industrial based projects have academic and industrial advisors as part of the working team.

The creation and expansion of the Learning Factory has provided a more attractive environment for students and faculty and has stimulated undergraduate and graduate research activities. Industry-based research projects have been developed to help small business with product development. We instituted a semester fair in Entrepreneurial Development, focusing on product design, with the participation of more that 20 teams of students. An extension of these efforts is the development of an Incubator Program with the Economic Development Administration of Puerto Rico.

University of Washington (UW):

The new option approach was approved last academic year and the 'pilot versions' have been initiated. The Mechatronics option currently has 25 students and the SAE Formula Car and the Human Powered Projects have a registration of 39 and 35 students respectively. Hence about 50% of the students in Mechanical Engineering and all the students in Industrial Engineering will be involved in significant design/build project activities this year. The challenge now is to involve other departments in the college, such as Electrical, Aeronautics and Astronautics, and Chemical Engineering to join. We are also looking for significant involvement of students from Industrial design (College of Arts and Sciences) and the School of Business.

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