Putting design and manufacturing back into the engineering curriculum

John S. Lamancusa - Penn State University
Jens E. Jorgensen - University of Washington
José L. Zayas-Castro - University of Puerto Rico- Mayagüez

Abstract

A new model is demonstrated for integrating design, manufacturing and business realities into the engineering curriculum. Called the ***Learning Factory,*** it is a new practice-based curriculum and physical facilities for product realization. Its goal is to provide an improved educational experience that emphasizes the interdependency of manufacturing and design in a business environment. The Learning Factory is the result of a desire to graduate better engineering professionals with technical competence in engineering science fundamentals as well as professional skills to effectively compete in today's market place. The key element in this approach is *active learning* - the combination of curriculum revitalization with coordinated opportunities for application and hands-on experience; thereby erasing the traditional boundaries between lecture and laboratory, academia and industrial practice.

As a result of this initiative, over 14,000 square feet of ***Learning Factory*** facilities have been built or renovated across the partner schools and are now serving hundreds of students. Five new courses which integrate manufacturing, design and business concerns and make use of these facilities have been instituted. These courses are an integral part of a new curriculum option in *Product Realization* which is now available at all three schools. They were developed by a unique team approach and their materials are available electronically over the Internet. The courses are: Product Dissection, Concurrent Engineering, Technology-based Entrepreneurship, Process Quality Engineering, and Senior Design Projects. Industry partners are providing real-world problems and are the customers for students in our senior capstone design courses. To date, 148 interdisciplinary projects have been completed across the three schools. These projects involve teams of students from Industrial, Mechanical, Electrical, Chemical Engineering and Business.

1. Introduction

A. The Need for Revitalizing Engineering Design Education:

The Learning Factory is the result of listening to the stakeholders in the education process - students, faculty and industry. Our industrial partners tell us that they can no longer afford to put new employees through lengthy training or apprenticeship programs. Newly hired engineers must be able to contribute to the good of the corporation in a relatively short period of time. In order to do so, they must possess strong technical competence in engineering science fundamentals, as well as essential professional skills that enable them to effectively apply those fundamentals to solve real problems. Students want to improve their marketability. They are asking for the chance to develop ingenuity as well as analytical capability. Faculty want to be effective educators but need new resources and facilities to reap the benefits of active learning.

The Learning Factory recognizes the need for both intellectual and physical activities in order to anchor the knowledge and practice of engineering in the minds of our students. While this approach is not really "new", it is part of the growing movement to reemphasize practice and hands-on experiences in engineering education. While the content of curricula, as well as the balance between theory and practice has dramatically changed over the decades[i], the predominant delivery method in most engineering schools today - the lecture - is relatively unchanged from that of a century ago. Lecture is a time honored, efficient technique for delivering large quantities of analytical information. In recent years, new findings in cognitive processes[ii] and behavioral psychology[iii] have demonstrated the limits of lecture, and alternatives to augment its effectiveness have been demonstrated[iv], including laboratories and cooperative learning.

Lectures encourage passivity in students, leading them to expect the instructor to provide all required knowledge. Lectures are geared toward the verbal learner, and do not take into account the varied learning styles of our students. Many engineers are in reality "visual learners", much better served by active, visual and tactile teaching methods[v]. Many students who have the intelligence and creativity to be excellent engineers find little fulfillment or stimulation in the rigid confines of the lecture hall, and drop out of formal engineering programs as a result. They do not see the relevance of their required courses to the actual practice of engineering. Too often these are promising minority or female students, to whom this lack of relevance and stimulation is sometimes "the straw that breaks the camel's back". Just as one cannot learn to drive without getting behind the wheel; or to swim without getting wet; entry into the profession of engineering, particularly in the area of design, requires far more than sitting in a lecture hall.

The National Science Foundation has recognized the opportunities to improve engineering education and is providing impetus to change by sponsoring several major education initiatives and coalitions[vi] including the partnership described in this paper.[1]

B. A Short History of the Manufacturing Engineering Education Partnership:

The Learning Factory is the product of the Manufacturing Engineering Education Partnership (MEEP). This partnership is a unique collaboration of three major universities with strong engineering programs (Penn State, University of Puerto Rico-Mayagüez, University of Washington), a premier high-technology government laboratory (Sandia National Laboratories), 100 corporate partners covering a wide spectrum of U.S. Industries, and the federal government that has provided seed funding for this project through the ARPA Technology Reinvestment Program (TRP).

The partnership draws on the special strengths of each member and provides a unique opportunity to share physical and intellectual resources and explore diverse educational approaches. Students at these institutions come from a wide range of geographic, socio-economic and cultural backgrounds. Together, these schools graduated 2,384 B.S. engineering professionals in the 1992-1993 academic year, all with the potential for significant impact on our nation's industrial competitiveness. Forty faculty members, across five time zones, are engaged in this effort.

The MEEP partnership owes its existence and success to four factors:

1. Firm belief in the need for increased emphasis on practice in engineering education, particularly for engineering design
2. Ground breaking activities at Penn State and the University of Washington by the NSF ECSEL Coalition.[vii]
3. The 1993 ARPA Technology Reinvestment Program (TRP) Solicitation
4. A common purpose and an unusual attitude of cooperation among the partners.

C. MEEP Objectives:

The specific objectives of our partnership are, 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.

2. Combining Theory and Practice

A. New Curriculum

Our curriculum is based on the direct linkage of theoretical studies with practice-based design and problem solving activities. **The Learning Factory**, in combination with the curriculum enables students to integrate design and manufacturing issues. Together, these developments produce an engineer ready for the 21st century, with the following qualities:

- Strong foundation in engineering science fundamentals;
- Well versed in the big picture of manufacturing and product realization, including the design process and business realities;
- Knowledgeable of current technologies and tools, and most importantly, their management and application to solve new problems;
- An effective team player;
- Adept at communication (oral, written, electronic); and
- Equipped and motivated for future learning.

This interdisciplinary curriculum, shown graphically in Figure 1, is available as a minor or a degree option at the participating universities. Several departments at each school are cooperating in this development, including: Mechanical, Industrial, Chemical, Electrical Engineering and Business. The curricula, consist of a progression of manufacturing/design courses, approximately one per term, and allows students to practice engineering science fundamentals in the solution of real problems.

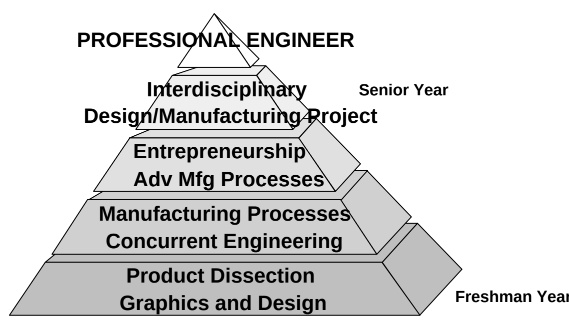

FIGURE 1. THE PRODUCT REALIZATION CURRICULUM PREPARES STUDENTS FOR PRODUCTIVE CAREERS IN DESIGN, MANUFACTURING AND PRODUCT REALIZATION

[1] TRP #3018, NSF Award # DMI-9413880

B. UPRM Certificate of Manufacturing

This certificate is being established in Industrial, Mechanical, Electrical and Chemical Engineering Departments. Basically, students utilize their technical and free electives to take 12-15 credits in manufacturing related courses. Six to nine credits are a common core based upon the courses developed by MEEP - product dissection, entrepreneurship and concurrent engineering- and the rest will be credits that will support a student's development in technical and business aspects related to manufacturing. The certificate will be administered by each department.

C. PSU Product Realization Minor

A 24 credit degree minor has been developed which will be available to all engineering students. The minor consists of a coherent series of courses in Design and Graphics (3 credits), Product Dissection (3 credits), Manufacturing Processes (6 credits), Process Quality Engineering (3 credits), Concurrent Engineering (3 credits), Technology Based Entrepreneurship (3 credits) and Interdisciplinary Senior Design Projects (3 credits). The minor is administered by the Industrial and Manufacturing Systems Engineering Department.

D. University of Washington

A major curriculum revision has been accomplished in the College of Engineering where the major departments have all reduced their credit requirements for 192 to 180 quarter credits. In addition, students can be accepted into departments by the sophomore year giving them better professional guidance and planning as well as allowing early access to engineering courses. The new curriculum will have a redefined technical core of 70 credits. A feature of the new curriculum is that it offers more flexibility and allows more technical electives (20 credits). Several "options" or "threads" are being developed (including consumer products, mechatronics, manufacturing process design and product realization) to take advantage of this flexibility. The Product Realization Option will consist Introduction to Design (4 credits), Product Dissection (4 credits), Concurrent Engineering (4 credits), Statistical Quality Control (3 credits), Entrepreneurship (3 credits) and Capstone Design (variable, 4 to 8 credits). Other combinations of upper division, elective courses with the College of Engineering and the School of Business Administration can be used to provide other viable options or threads.

E. Instructional Design Considerations

The MEEP curriculum builds on existing courses in graphics, design, and manufacturing processes. The instructional design emphasizes interactivity on two distinct levels. First, the courses are integrated into the students entire academic program, from introductory freshman courses to senior year design project experiences. In this manner, student-student, student-teacher, student-industrial partnering is fostered over the years, preparing the student for the leap from the classroom into industry. Second, the curriculum is much more than just lecture-based design. It incorporates case studies, problem based learning, active learning techniques, and interactive multimedia computer technologies in the classroom. Previously unavailable opportunities for hands-on engineering experience are provided in the facilities of the Learning Factory.

As part of the new curriculum, several new courses have been developed across the partnership. In addition, a number of existing courses have been modified to take advantage of the Learning Factory concept including courses in Robotics, and Manufacturing Processes. The courses currently being developed by MEEP are described below.

Product Dissection*:* This course examines 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. The primary objectives of this course are to develop a basic aptitude for engineering and engineering design, and to develop mental visualization skills by examination of the design and manufacture of consumer and industrial products. This course is intended to complement engineering science and mathematics courses and to show students how these fundamentals relate to engineering practice.

Concurrent Engineering: This course presents the origin and meaning of the term *concurrent engineering* and discusses its role in modern engineering companies. Students gain an appreciation for the role of a formal product/process development strategy, and learn how to use tools such as team decision making processes, value engineering, quality function deployment, project networks and planning, failure mode and effects analysis and DFM/DFA assessment tools. Also discussed are life cycle issues such as safety, reliability, maintainability and product disposal. Case studies from various industries provide students with a broad vision of concurrent engineering, and industry speakers present a practical perspective.

Technology Based Entrepreneurship: This course is developed in conjunction with the School of Business and provides students with the fundamentals of entrepreneurship. It is designed for engineering, science, and business students interested in learning about entrepreneurship from a technology and practice-based point of view. The emphasis of the course is on innovation and creativity. Topics include: market analysis, problem and idea selection, prototyping, and product design.

Process Quality Engineering: This course 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 includes eight laboratory sessions, where students design their own experiments, collect data, and apply appropriate statistical analysis tools to that data.

Interdisciplinary Senior Design Project: This 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 our industry partners. This project activity ideally spans a full academic year.

The educational objectives of our curriculum, i.e. the desired skills which we want our students to develop, are listed in Table 1 as well as their level of integration into the MEEP courses. These skills were determined by our Industry Advisory Board and represent their view of the capabilities required by the practicing engineering professional.

TABLE 1. DISTRIBUTION OF SKILLS AND KNOWLEDGE THROUGH NEW COURSES

CURRICULUM THEMES	Product Dissection	Concurrent Engineering	Entrepren-eurship	Process Quality Engineering	Senior Design Project
Engineering Science Fundamentals	P	P	P	P	P
Design/Synthesis	B	B	B	B	A
Probability Methods	N/A	N/A	N/A	A	A
Materials (Selection, Non-Traditional)	B	P	P	O	A
Creativity	B	O	B	O	A
Manufacturing Processes	O	P	P	O	A
Communication Skills	B	A	A	B	A
Team Skills	B	A	A	A	A
Problem Solving Skills	B	B	P	B	A
Total Quality	N/A	A	A	B	A
Business Concerns	O	B	A	O	A
Project Management	O	A	A	N/A	A
Cross-Disciplinary Industrial Projects	N/A	A	A	O	A
Environment and Societal Concerns	B	A	A	N/A	A
Integration of Product/Process	B	A	A	O	A

Legend: O=Overview B=Basic A=Advanced P=Prerequisite N/A=Not Applicable

F. Course Development Process

Curriculum and laboratory development are time consuming and costly processes. The partners are dedicated to the philosophy that sharing of resources and ideas, avoiding redundant efforts, utilization of new technologies for communication, and achieving consensus on curriculum content are critically important. Our mission is to jointly develop curriculum materials that are easily transportable and utilized among the MEEP partners, and exportable to the academic community at large. Ultimately, all course materials will be available on Internet over the World Wide Web.

Course development consists of a four part process:

1) Planning - coordinators from each school agree on overall course objectives and content and how that course fits into the balance of the curriculum
2) Piloting - one school takes the lead role in developing the course specifics and offering it on a trial basis
3) Publication - The piloting school makes all course materials available in electronic format for use by other schools.
4) Deployment - The remaining schools apply the course materials and offer the courses, making whatever modifications are necessary to satisfy unique institutional requirements.

The development process is shared over the partnership as shown in Table 2. Communication and consensus-building are accomplished by regular face-to-face meetings (approximately two per year) and extensive use of electronic mail and teleconferencing. Each course development group includes at least one undergraduate student, providing an indispensable “customer” viewpoint.

TABLE 2. SHARING OF CURRICULUM DEVELOPMENT EFFORTS ACROSS THE PARTNERSHIP

Course	Piloting Institution	Pilot Offering	Offering across MEEP	Export
Product Dissection	Penn State	August 94	Fall 95	Summer 96
Concurrent Engineering	Washington	September 94	Fall 95	Summer 96
Entrepreneurship	Puerto Rico	January 95	Fall 95	Summer 96
Process Quality Engineering	Penn State	January 95	Fall 95	Summer 96

3. The Learning Factory

Physical facilities for manufacturing and product realization, located at each partner institution, are the cornerstone of our efforts. Across our coalition, over 14,000 square feet of new and remodeled facilities, equipped with state-of-the-art equipment, are devoted to this activity. The Learning Factory at the University of Washington is illustrated in Figure 4. The basic principle of the Learning Factory is integration — integration of design and manufacturing experiences into the undergraduate curriculum; integration of equipment and materials into manufacturing systems; and integration of people from several engineering and business disciplines into effective teams that design and produce products and processes.

The Learning Factory is an activity-based facility which is designed to be used across the curriculum. It therefore differs from traditional, highly focused, disciplinary labs that are tied to specific courses such as fluid mechanics, electronics, or an automatic controls laboratory. The Learning Factory is the focal point of the product and process realization activities in design and manufacturing and draws on the specialized resources of the disciplinary labs where appropriate to support the courses. It is “dynamic” or agile, in that the student activities define its use and structure. For instance, the Product Dissection course uses Learning Factory facilities (model shop, design studio, CAD/CAM, Metrology, Manufacturing Processes) as well as disciplinary labs (Electronics, Computing, Materials and Mechanics, Composites Processing).

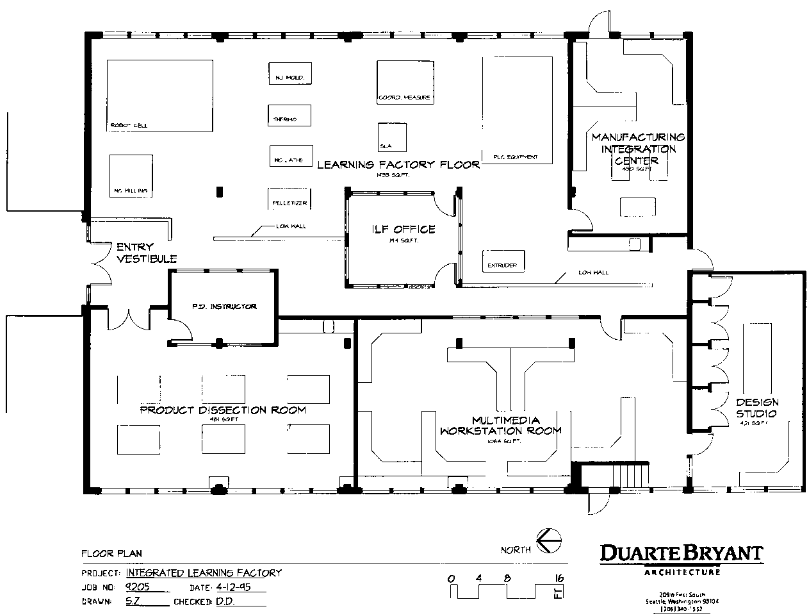

FIGURE 4. THE LEARNING FACTORY AT THE UNIVERSITY OF WASHINGTON (6600 ft^2)

In the Learning Factory, students actively experience the product realization process in its entirety, from design concept to finished hardware. Our vision is a facility where students continually seek to implement their ideas, hone their skills and practice engineering in an environment similar to an industrial setting. We seek an experience where every academic term, students participate in a course that uses the Learning Factory as an integral part of its syllabus. For example, in the sophomore year, students in Product Dissection benchmark products, document designs using CAD equipment, perform measurements, critique manufacturing and design decisions and use prototyping facilities to implement their ideas for product improvement. Sophomores and Juniors are likely to be found honing their basic manufacturing process skills, and directly experiencing the interdependency of design and manufacturing covered in Concurrent Engineering. Seniors in the design projects class work in cross-disciplinary product teams on a wide variety of projects requiring the use of advanced design and manufacturing concepts and facilities. The needs of our industrial affiliates are a prime source of these projects. Other projects revolve around student design competitions sponsored by the various professional societies (including SAE vehicle competitions), or student inventions resulting from the entrepreneurship class or independent studies.

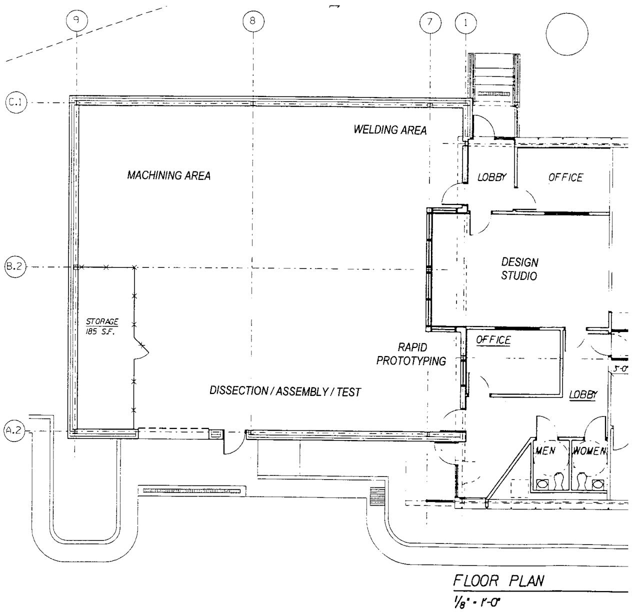

FIGURE 5. PENN STATE'S LEARNING FACTORY (3500 ft^2)

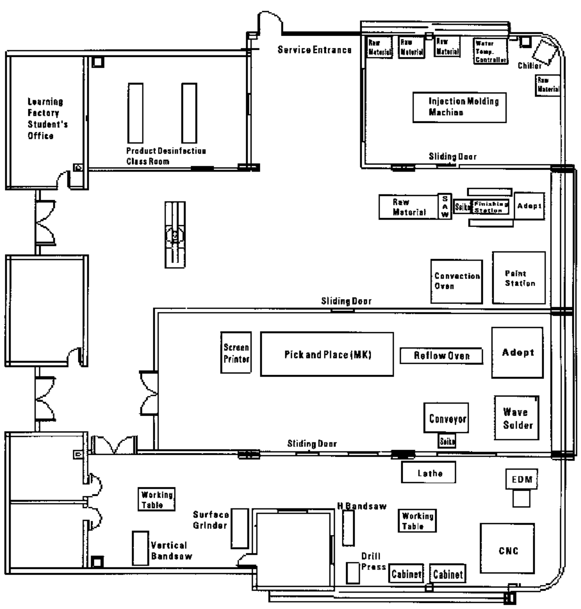

FIGURE 6. THE LEARNING FACTORY AT THE UNIVERSITY OF PUERTO RICO (4000 ft^2)

4. Industry Partnership

A critically important element in this operation is our Industry Partnership. Each university has a board of industry representatives who are convinced of the value of the Learning Factory and are volunteering their time to make this effort a success. The contribute their time, equipment, senior design projects and funds. The fact that these important people continue to donate their time is indicative of the merits of our activities and the benefits they perceive in this interaction.

One particularly successful model has been for this group to meet twice each semester to critique our efforts and offer strategic guidance. At the beginning of each semester, part of the meeting is devoted to a presentation of available senior design projects. Corporate sponsors meet with the seniors in our ME, IE and EE capstone design classes to present potential projects for the students to work on during that semester. This event gives students the chance to network with potential employers, hear firsthand about what it is like to be a practicing engineer, and learn subtleties like professional dress and presentation skills. At the end of the semester, the same parties reconvene in the ballroom of a local hotel for "Senior Projects Day". At that time, it becomes the students' turn to present their project results, via high quality posters and an oral presentation. The audience for this event consists of the industrial sponsors, students in all the senior design classes, faculty, students interested in Product Realization, the public and the news media. This event is one of our primary vehicles for promoting the Product Realization Minor to prospective students. It has also been very valuable in promoting the Learning Factory concept to our faculty colleagues.

In order to be successful, this partnership must be mutually beneficial to industry and academia.

Industry partners directly benefit from this partnership by:

- Availability of well-prepared engineering graduates who understand the product realization process;
- Opportunities to evaluate potential employees through internships, collaborative projects and classroom interactions;
- Direct assistance in product and process design problems through sponsorship of senior design projects;
- Professional development of industry personnel through teaching, learning factory and curriculum development;
- Technology transfer through Industrial-Academic exchanges - industry engineers in the classroom, and faculty internships in industry; and the
- Opportunity to influence and improve the education of engineers well into the next century.

The members of our industrial partnership span the spectrum from large multi-national corporations to small family-owned businesses. Represented industries include aerospace, automotive, electronics, pharmaceuticals, chemicals, computers, machine tools and consumer products. Each member brings with it a unique perspective and a valuable contribution. The current industrial affiliates of this project are:

TABLE 3. INDUSTRIAL PARTNERS OF MEEP

Abbot Labs	Accusort	Allegheny Valve
Allergan Medical	AMP	AT&T
Atotech	Avon	Baxter Biotech
Baxter Edwards	Bently Systems	Boehringer Labs
Boeing	Bristol Myers - Squibb	Caribe GE
Conair	Cutler Hammer	Dana Corp.
D/E Associates	DEC	DuPont
Eastman Kodak	ELDEC	ExtrudeHone
FF Industries	FLOW Int. Corp.	Fluke
Foundry Education Foundation	FORMOST	GBC Materials
General Electric Lighting	General Electric Ohio Lamp	General Instrument
General Motors	Globe Lift	Haleyville Mfg.
HealthTech	Henrob	Hewlett Packard
Holman Inc.	Hop Scotch Restaurant	IBM
Husky Injection	Industrial Dielectrics	Industrial Modernization Center
InFlow Inc.	Innoteck Inc.	Jack Ogle and Co.
JLG Industries	K2	Kennemetal
Kimberley Clark	Lifescan	Lutron
MARCO	Martin Consulting	Microsoft
Motorola	Muncy Machine Tool	Murata Electronics
New Holland	Northwest Pacific Fishing	Novatek
NYPRO	Olympia Orthotics and Prosthetics	PAC Northwest
PACCAR	Piezo Kinetics	Plastics Systems
Polymerland	Precision Components	PRECOR USA
PREMSCO	Procter and Gamble	Productos La Aguadillana
Professional Molding	Puerto Rico Manufacturers Assoc.	PR2000
PR Economic Development Adm.	Red Dot	Rolodex
SPE	Seafirst Bank	Security Plastics
Sensormatic	Stryker/Arroyo	Supertechnology
Taylor Packing	Techno-Plastics	Tektronix
Telecomm Solutions	Textron Lycoming	Upjohn
USDA Forest Service	Vasallo Paints & Coatings	Washington Technology Center
Wash. St. Recycle Assist. Program	Westinghouse	Wenzel and Associates
Xerox		

These partners contribute in several critical ways, providing physical and personnel resources including:

- Manufacturing/design student projects
- Practicing engineers in the classroom (guest lecturers, design project supervisors)
- Opportunities for faculty experiences in industry
- Donations and loans of equipment
- Direct financial support
- Summer student internships
- Expertise to develop Learning Factory facilities
- Tours of industrial facilities for students and faculty
- Assistance with course development (such as case histories)
- Feedback on MEEP curriculum developments
- Strategic guidance in matters of fund-raising and management

5. Outreach

The MEEP partnership is dedicated to changing engineering education and ensuring that the benefits of those changes are available to all students. Our approach will attract outstanding students who wish to supplement the traditional lecture environment with real-world experiences in the Learning Factory. The approach will also help retain those students who are not stimulated by the traditional lecture environment, but who have the intellectual and creative abilities to become exceptional engineers. Our curriculum materials are modular, transportable and available to the academic community at large. Extensive use is made of electronic techniques for communication and curriculum export, such as multi-media computer tools, the National Information Infrastructure, and video conferencing. Our outreach activities are coordinated by our partners at Sandia National Laboratories.

Portability of curriculum across platform, editability of files by faculty, and accessibility of files over the Internet were key considerations for the outreach activity. Ease of access issues are continually being addressed. For example, a style guide with a template for format issues is shared among authors to ensure that files may be imported and printed without difficulty on any platform. Consistency of presentation was a minor problem eradicated by the implementation of the style guide, enabling authors to employ the same font, format, point size, and powerpoint template, for a coherent look and feel for all materials developed by the partnership.

The Outreach goals evolved over the two-year partnership. Early in the curriculum development phase, outreach within the participating universities was paramount, now, one year into the project, outreach beyond the three universities is critical. Initially, files were shared via file transfer protocol (ftp) at anonymous ftp sites at the University of Washington and at Penn State. A limited number of CD-ROMs were issued containing course notes and lecture materials in Microsoft Word and Powerpoint files. Multimedia elements were developed using Authorware software (by Macromedia Inc.), in part because of the power, ease of construction, and runtime costs on either MAC or PC platforms. Finally, a site was developed on the World Wide Web to advertise the availability of the curriculum and to demonstrate highlights of the learning factory approach to the engineering community at large (http://lfserver.lf.psu.edu). Other information, like conference papers, links to other exemplary engineering and design curriculum web sites, and student/faculty responses to MEEP are also on-line.

6. Impact and Assessment

The overall impact of this project has been to change the academic culture. The key lever in achieving this has been the positive influence of our industrial partners. From the industry perspective, we finally have a concept (the Learning Factory) that they understand, appreciate and wholly embrace as more fully meeting their needs. Their enthusiasm has translated into the beginning of change in the attitudes of faculty members - that a hands-on educational environment, in concert with engineering science, is a valid approach. This approach has academic merit, is becoming more rewarded by universities, need not be exorbitantly expensive, and clearly provides a superior education to our students. Across the coalition, four new courses have been developed, taught and are becoming part of new curricula in Product Realization and Manufacturing. Specific accomplishments of this program at the three universities are described below. These accomplishments illustrate the richness and diversity of the coalition approach and attest to the cross-fertilization engendered by this partnership.

A. Penn State Accomplishments

After 4 semesters of operation, the Learning Factory project at Penn State can boast of several major achievements:

- Four new courses have been instituted at Penn State (Product Dissection, Concurrent Engineering, Entrepreneurship, Process Quality Engineering)
- Seven existing courses have been revised (IE328 Production Engineering, ME415 Senior Design Project, ME414W Thermal Design, IE430 Industrial Projects, ME456 Robotics, ME452 Vehicle Dynamics, ENGR297 Enigmatic Engines) to take advantage of the Learning Factory facilities.
- A new 3,500 square foot Learning Factory facility has been built, equipped, staffed
- 50 industry-sponsored interdisciplinary senior design projects have been completed
- 21 industry partners are actively contributing projects, support and supervision.
- Over 1500 students from 5 engineering departments have used the Learning Factory in their courses or projects. Usage has approximately **doubled** each semester.
- The minor in ***Product Realization*** has been developed, approved and instituted by the university
- We have instituted "Projects Day" at the end of each semester to showcase senior design projects and to facilitate industry-student interactions.
- The project team has received a highly competitive *Provost's Award for Collaborative Instruction and Curricular Innovation.*
- Our efforts were featured in an article in the New York Times, Education Life Magazine on April 2, 1995[viii].

B. University of Washington Accomplishments

After 16 months (5 quarters) of operation we can claim the following accomplishments at the University of Washington:

- 450 students have been involved in MEEP related courses and activities
- A new curriculum with a pathway (or option) in Product Realization has been adopted by Industrial and Mechanical Engineering and will become university-approved by the Autumn of 1996
- New courses in Product Dissection, Concurrent Engineering, Entrepreneurship, and Process Quality Engineering are now offered regularly, cross-listed and co-taught by several departments.
- The Learning Factory, with 6,500 square feet of renovated space and up-graded equipment, will be fully operational by the summer of 1996.
- Twenty-five industry and university (related to research in rehabilitation medicine, forestry and bio-mechanics) sponsored senior Capstone Design have been executed by IE and ME students. These projects have benefited from the Learning Factory, which is currently operating in temporary facilities.
- Student entries and participation into national competitions such as the SAE Formula Vehicle , the ASME Human Powered Submarine, and the RAVEN Human Powered Plane are now a major part of the students professional development.
- A paradigm shift in instructional attitudes among both the faculty and students is taking place. Courses are co-taught by faculty and industry participants. In the classroom collaborative learning, where students are working effectively in teams, is now a reality. And, we are all having fun.
- Faculty from the University of Washington, Washington State University and Tacoma Community College are jointly participating in a NSF sponsored program to extend the products and processes related curriculum developments at the entry (freshman and sophomore) level to the community college system.

C. University of Puerto Rico-Mayagüez (UPRM) Accomplishments

The MEEP initiative has had a tremendous impact at the University of Puerto Rico-Mayagüez. More than 500 students have been positively affected by their participation in course work, Learning Factory, industry based projects and interaction with other students at participating universities. Over 60 industry based projects have been coordinated and we have had an industrial based sponsorship exceeding $750,000 from more than 50 industrial sponsors. Furthermore we have been able to effectively promote practice-based learning (in courses: Product Dissection, Concurrent Engineering, Entrepreneurship, Capstone Design and Process Quality Engineering) team teaching (Entrepreneurship course), collaborative learning and interdisciplinary participation. Currently there are five disciplines participating in this effort at UPRM: Industrial, Mechanical, Electrical and Chemical Engineering and Business Administration. In addition various initiatives have been developed with the Colleges of Arts and Sciences and Agricultural Sciences. During the first year a student exchange was established with PSU which will be expanded to include UW and Sandia. The creation and expansion of the Learning Factory has provided a more attractive scenario for students and faculty and has stimulated undergraduate and graduate research activities. In addition industrial-based projects have been developed to help small businesses with product development. An extension of this effort is the development of an Incubator Program with the Economic Development Administration of Puerto Rico.

D. Assessment

A formal assessment of the project outcomes and deliverables is underway and is a requirement of the ARPA project monitor. The assessment methodology has the following elements:

- internal (self-assessment)
- external (outside the partnership)
- multiple criteria (variety of modes and viewpoints)
- holistic (integrated)
- qualitative and quantitative components

7. Future Challenges and Opportunities

The major challenge and opportunity now facing MEEP is to continue these activities after the federal funding has expired. Each institution is in the process of establishing permanent funding mechanisms to support future operations. These funds will come from a mixture of university and industry sources. Additional challenges include: broadening participation to include more engineering and business departments; marketing and continuous quality improvement of the Product Realization courses; disseminating curriculum materials to interested universities; convincing faculty colleagues of the scholarly content of educational activities; and expanding our base of industry partners in order to insure that our efforts continue to meet the needs of US. Industry.

8. Conclusions

A unique partnership of universities, industries, and the federal government has been formed to revitalize design and manufacturing engineering education. This partnership has developed an integrated curriculum and physical facilities for product realization at each university, with the full cooperation and assistance of 36 industrial partners. The primary products and benefits of this coalition to students, industry and faculty are:

- superior engineering graduates who are well prepared to impact overall business productivity;
- a new paradigm for engineering education based on a balance among analysis, design, processing and integration;
- practice-oriented teaching modules, available electronically;
- and greater prestige for manufacturing and design education in university curricula.

A number of important conclusions are apparent from this project, specifically that:

- A coalition of faculty from diverse institutions can effectively collaborate and produce results far superior to what is possible by individual achievement.
- The traditional academic culture in engineering can be influenced to change.
- Active learning, as achieved by the Learning Factory, is an effective method for educating engineering students.

References

[i] The Making of an Engineer - An illustrated history of engineering education in the United States and Canada, Lawrence Grayson, John Wiley and Sons, 1993.

[ii] Cognitive Aspects of Learning and Teaching Science, Jose P. Mestre, Pre-College Teacher Enhancement in Science and Mathematics: Status, Issues and Problems, S. J. Fitzsimmons and L.C. Kerpelman (Eds.), Washington DC: NSF

[iii] Toward a Strategy for Teaching Engineering Design, Billy V. Koen, Engineering Education, 83(3), July 1994, pp 193-202.

[iv] A Different Way of Teaching, P.C. Wankat, F.S. Oreovicz, ASEE Prism, January 1994, pp 15-19.

[v] Learning and Teaching Styles in Engineering Education, R.M. Felder, L.K. Silverman, Engineering Education, 78(7), April 1988, pp 674-681.

[vi] Engineering Education Coalitions-Meeting the Need for Reform, National Science Foundation, publication NSF 93-58a

[vii] ECSEL Coalition (Engineering Coalition of Schools for Excellence in Education and Leadership) -- A Foundation for Educational Change, M.L. Walker Jr, J.R. Bowen, and B.B. Schimming, Proceedings of 23rd Frontiers in Education Conference, Crystal City, VA, Nov 1993, pg 35.

[viii] The New York Times, Education Life Supplement, Section 4A/April 2, 1995

Biographical Information

John S. Lamancusa, Co-Principal Investigator for Penn State, is an associate professor in mechanical engineering. Before coming to Penn State in 1984, he was employed at AT&T Bell Laboratories where his technical responsibilities included electronic packaging, product design for automation and acoustic design of business telecommunications equipment. He received his Ph.D. in mechanical engineering, with a minor in electrical and computer engineering, from the University of Wisconsin-Madison in 1982. Dr. Lamancusa earned his B.S. in mechanical engineering from the University of Dayton in 1978. His areas of academic research and industrial consulting include mechanical design and design optimization, design for manufacture, noise and vibration control, musical acoustics and mechatronics.

Jens Jorgensen ,Co-Principal for the University of Washington, has served as a University of Washington faculty member since receiving his Ph.D. in mechanical engineering from MIT in 1969. His area of specialization is design and control of dynamic systems, with a concentration on manufacturing systems. His extensive collaborations with industry and government agencies include work for Weyerhauser, Boeing, and the USDA Forest Service. He helped to establish the Manufacturing Systems Center of the Washington Technology Center and was its director from 1983 to 1990. He has been actively involved in teaching undergraduate students for 33 years. He was the UW principal investigator for the NSF sponsored ECSEL coalition that initiated a new paradigm in the teaching of design and practice based engineering. In 1993 he received the "Academic Engineer of the Year" from the Puget Sound Engineering Council.

José L. Zayas-Castro**,** Co-PI for the University of Puerto Rico - Mayagüez, has a B.S. degree in Industrial Engineering from UPR-Mayagüez (1978), and M.S. in Industrial Engineering (1979), MBA (1981), and Ph.D. in Management (1983) from Rensselaer Polytechnic Institute. Dr. Zayas conducts research and consulting in statistical process control, productivity improvement, information flow and office automation, manufacturing and business strategy, manufacturing and business strategy, economic and cost analysis, manufacturing simulation, and general management. He is a professor in the Industrial Engineering Department, for which he served as department head between 1987 and 1990. He is the director of the IE microcomputing center, co-coordinator of the Manufacturing Laboratory, and directs the Institute for Innovation in Manufacturing.