THE LEARNING FACTORY OF THE MANUFACTURING ENGINEERING EDUCATIONAL PROGRAM

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ABSTRACT

The Learning Factory is a facility that supports product realization within a new practice based, engineering curriculum developed and adopted by the participating universities of the Manufacturing Engineering Education Partnership (MEEP) bringing together Pennsylvania State University, University of Puerto Rico @ Mayaguez, and University of Washington with Sandia National Laboratories and its corporate partners.

The learning factory is an activity based facility designed to tightly link activities in the class room with hands-on experience. The design and implementation is intended to allow students to hone their skills and practice engineering in an environment emulating an industrial setting.

I. INTRODUCTION

The Manufacturing Engineering Education Partnership (MEEP) consists of Penn State, The University of Puerto Rico-Mayaguez, the University of Washington, Sandia National Labs, and its industrial affiliates. The MEEP partnership owes its existence to a firm belief in the need for increased emphasis on practice in engineering education, particularly for engineering design and realization of the design through manufacturing. In short, the idea is to build what one designs. On July 15, 1994, MEEP received funding from the ARPA TRP to support a two year experiment. This paper will attempt to describe our approach to curriculum revision and the role of the Learning Factory in this restructuring

The Partners: The Manufacturing Engineering Education Partnership (MEEP) brings together the strong engineering programs of the above mentioned three major universities with a premier high-technology government laboratory and corporate partners covering a wide spectrum of US. Industries. 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, in the 1992-93 academic year, these schools graduated 2,384 BS. engineering graduates with the potential for significant impact on our nation's industrial competitiveness.

The MEEP Objectives: The specific objectives of our partnership are to develop:

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

The overall aspect of our program was presented earlier by Lamancusa et. al.[1]

II. INTEGRATION OF THEORY AND PRACTICE INTO ONE CURRICULUM

The Curriculum Changes Direct linkage of theoretical studies with practice-based design and problem solving activities forms the basis of the “new” curriculum. Integrally coupled to the curriculum, *The Learning Factory* enables students to integrate design and manufacturing issues. Together, these developments will produce an engineer 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, a Product Realization Minor, is now available as a degree option at the participating schools and is offered through the cooperation of several departments, including Mechanical, Industrial, Chemical, and Electrical Engineering, as well as Business. The curriculum, as shown in Figure 1, consists of a progression of design and manufacturing courses, approximately one per term (or quarter), allowing students to practice their engineering science fundamentals in the solution of real problems.

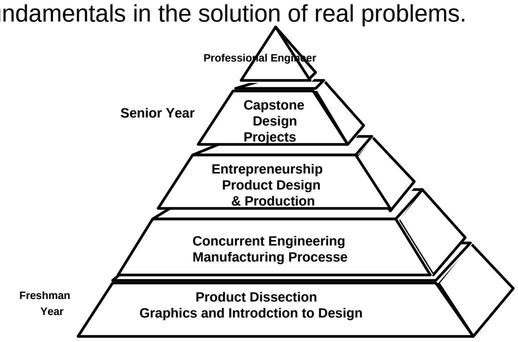

Figure 1. The course curriculum in the Products and Processes Realization Program to be supported by the Learning Factory

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. 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: This course presents 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 focuses on helping undergraduate engineering students gain an appreciation for customers, the business aspects of successful design, and manufacture and marketing of technology-based products and services. Students will gain first hand knowledge and appreciation of the relationships among product performance, customer needs, and business constraints by developing their conceptual ideas into marketable products and services.

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 provides a laboratory experience, 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 industry. The project activity ideally spans a full academic year.

The Learning Factory Concept

The Learning Factory is an activity-based facility which is designed to be used across the curriculum. It therefore differs from the traditional, highly focused, disciplinary labs that are tied to specific courses such as fluid mechanics, electronics, or controls. These courses have laboratories that are well defined in terms of their objectives, principles to be investigated, and skills to acquired. In the Learning Factory, students are actively experiencing a product, or a process, realization in its entirety, from initial design concept, through rapid prototyping, 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 emulating an industrial setting. We seek an experience where each semester (or quarter), students participate in a course that uses the Learning Factory as an integral part of its syllabus. The conceptual design of the learning factory is indicated in Figure 2

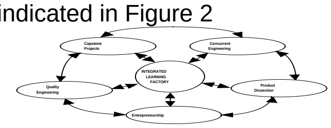

Figure 2 Learning Factory Concept

In the freshman 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, or student inventions resulting from the entrepreneurship class or independent studies.

III. THE INTEGRATED LEARNING FACTORY IMPLEMENTATION

Physical facilities for manufacturing and product realization, located at each partner institution, are the cornerstone of our efforts. Across our partnership, over 14,000 square feet of new and remodeled facilities, equipped with state-of-the-art equipment, are being devoted to this activity. 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. While each of the schools have developed LF's with certain commonalties they also represent regional differences based on local industry input and expertise. The basic implementation concept is shown in Figure 3

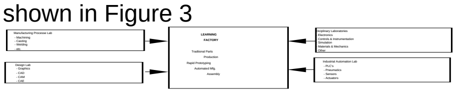

Figure 3 Learning Factory Implementation Concept

In the implementation we adopted the following strategy across the partnership:

* Support all courses and activities in the new curriculum
* Create an industrial manufacturing environment
* Be able to go from rapid prototype to finished product
* Have a design studio, model shop, assembly and test facilities
* Network facilities at each institution
* Provide specialty services to the partnership

Figure 3 illustrates, in a generic manner, how we envision the integration of existing disciplinary laboratory facilities such as electronics, controls, etc., into the LF concept. Additional aspects of the Learning Factory is that is provides infrastructure and resources to courses and the needs of the capstone design and entrepreneurship activities. At each of the MEEP institutions the Learning Factory "floor" received a slightly different implementation influenced by the local industrial conditions described in the following sections.

University of Puerto Rico @ Mayaguez The basic philosophy of this laboratory is the integration of equipment, materials, and people into manufacturing systems, as well as the integration of people from several engineering and business disciplines into working teams that specify, design, implement, and operate such manufacturing systems. The main component of the UPRM Learning Factory will be a series of actual production lines that will produce real products (see figure 4). Other laboratories through the UPRM campus provide support to the Learning Factory.

Within the next five years the Learning Factory will have three to four actual production lines that will be specified, designed, installed, and operated by several teams of students (graduate and undergraduate), professors, and industry representatives. The current line is producing a family of desktop products made of tubes and sheets of PVC plastic cut to different sizes and shapes and assembled into the final products. The intent of this production line, designed and built by student/faculty teams, is mostly educational.

Future production lines are expected to concentrate on products with a higher commercial value and will be a strong reflection of the types of products/processes found in local industry. This includes a surface mount technology (SMT) electronics assembly line that is expected to be completed within the 1995/96 academic year. An injection molding line is also under design and is expected to be completed within the next two years. Finally, a tablet manufacturing line is planned for the more distant future. These projects all have industry endorsement and sponsorship.

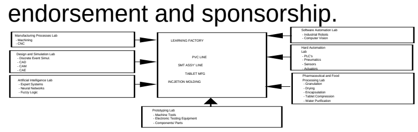

Figure 4: UPRM Learning Factory and Supporting Labs.

It is expected that the production lines in the Learning Factory will be dynamic in nature as enhancements are added and new products designed and produced. Each line is expected to have a useful life of five to ten years after the initial implementation.

Satellite laboratories support the activities in the Learning Factory (see fig. 4). These laboratories, for the most part will be used to investigate and to teach more in depth the technologies used in the Learning Factory and to develop the products and processes used in it. The satellite laboratories departmental laboratories located throughout campus.

Penn State University and the University of Washington The industrial communities served by these two universities are diverse with respect to their products, their manufacturing processes, and their size. In common are their diversity and the challenge imposed by the interdisciplinary nature of the design/manufacturing teams they employ. The concept implementation, arrived at through faculty team deliberations, is one that provides design and manufacturing (prototype) under one roof (see figure 5).

The combination of the design studio and multi-media facilities provides the students with workstations, printers and plotters, drafting tables, a conference table, and book shelves loaded with design and manufacturing trade journals, supplier catalogs, and the Thomas Register. The workstations are equipped with CAD software, engineering analysis packages, and office and project management applications.
The manufacturing floor provides for a variety of manufacturing process including material removal, sheet metal and tube bending, welding and press work, and shot blasting. In addition, the facility supports a model shop, assembly processes and metrology. Future expansion will include the ability for rapid prototyping.

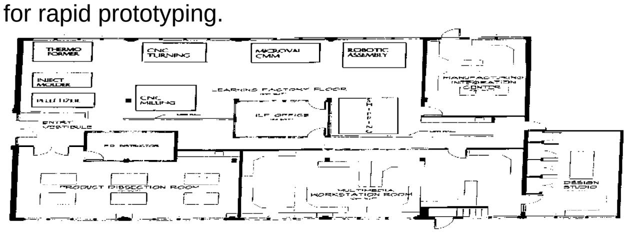

Figure 5 UW Learning Factory Implementation

The product dissection room is a facility dedicated to teaching students about parts and product design. Starting with the dissection process the facility will see expanded use in the teaching of components design and their integration into a product or system. Artifacts can be stored and retrieved for use as needed, and complements of tools and simple test instruments are provided.

The Learning Factory will support a large number of activities during the 1995/96 academic year. These include the Product Dissection and Entrepreneurship courses. In the latter, the students will prototype their ideas for market surveys. Both schools have been involved in the SAE formula car that will be designed and produced in the LF. At the UW the students are also involved in the national Human Powered Submarine competitions. Industrial projects for the senior capstone design will provide the bulk of the LF activities with specialty offerings of topics such as process design and tool design for prototype and volume production (Penn State only).

Learning Factory Administration and Operation

The learning factory is staffed by a Director who is also a faculty member, a staff LF Coordinator and graduate student teaching assistants. The director coordinates facility usage with the teaching staff of the PRM courses. In addition, the Director will serve as the liaison with the industrial partners, seek donations of capital equipment and materials, and continue the development and up-grade of the LF facilities. In the future, it is envisioned that this role will be expanded to include the coordination of industry workshops within the facility.
The LF coordinator's responsibilities include technical administration of the LF, technical and skill training of the teaching assistants, and supervision of undergraduate students. The graduate teaching assistants are a mixture of dedicated LF TA's and course TA's. The LF TA's responsibilities include the training and supervision of the undergraduate students when they are working in the LF. The course TA's are dedicated to specific courses (capstone design, entrepreneurship etc.) and provide the more traditional help in design analysis, CAD, and simulation. However, in order to support the LF within their particular course they are expected to dedicate roughly 4 hr/week to the LF, performing tasks similar to the LF teaching assistants.

All TA's are expected to have generalized skills in order to supervise students using any of the resources within the facility. In addition, each TA is expected to become an expert in the usage of a particular resource and to develop and administer a short course for the undergraduate students on that resource. These short courses are provided to PRM students during normal course lab hours and in the evening.

6. SUMMARY

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

* 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;
* Model practice-oriented engineering education curriculum elements, packaged as tested teaching modules and transferable from institution to institution.
* Greater prestige for manufacturing and design education in university curricula;
* Opportunities for students, faculty and engineers to exchange location, technology, ideas and products across a wide geographic and cultural spectrum.

Key Words:

Curriculum development. Manufacturing education. Learning factory. Product realization. Course and laboratory integration. Just in time education. Team learning

[1] Lamancusa, J. S., J. E. Jorgensen, J. L. Zayas-Castro, and J. Ratner, "THE LEARNING FACTORY - A new approach to integrating design and manufacturing into engineering curricula" Proc. ASEE Annual Conference, Anaheim, CA, June 1995