# THE LEARNING FACTORY
## Curriculum Integration Of Design And Manufacturing

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## ABSTRACT

The Learning Factory is a facility that supports product realization within a new practice based, engineering curriculum. The curriculum has been developed and adopted by the participating universities of the Manufacturing Engineering Education Partnership (MEEP). This partnership is a unique collaboration of three major universities with strong engineering programs (The Pennsylvania State University, University of Puerto Rico- Mayaguez, University of Washington), a premier high-technology government laboratory (Sandia National Laboratories), corporate partners covering a wide spectrum of US. Industries, and the Federal Government that is funding this project through the Technology Reinvestment Program (TRP).

The partnership has completed it first academic year. During this period, a new curriculum option was created and Learning Factories established to support the course developments and industrially sponsored, senior design projects. The new curriculum, the Product Realization Program, is an option that allows students to integrate the activities of design and manufacturing and the Learning Factory is a key components of this integration. Two different Learning Factory paradigms were developed in order to adapt to the differing industrial environments of the partnership universities.

The industrial partners of The Pennsylvania State University and the University of Washington are diverse with respect to products manufactured, manufacturing processes employed, and size. Hence, the Learning Factories at these universities were developed to support the design, analysis, and manufacture of prototype products and processes.

In contrast, the industrial partners of the University of Puerto Rico are primarily associated with pharmaceutical manufacture, discrete plastic part manufacture, and printed circuit board assembly. All of these partners utilize high volume, automated production lines. Consequently the development of the Learning Factory at the University of Puerto Rico has been centered around dedicated production facilities for tablet manufacture, plastic injection molding, and printed circuit board assembly. Senior design projects at the university have involved the construction, modification, and operation of these production facilities. This paper will describe the concept, implementation and operations of the learning factory.

### I. INTRODUCTION

"THE LEARNING FACTORY -- Curriculum Integration of Design and Manufacturing " recognizes the need for both the intellectual and physical blending of activities as a necessary means of anchoring both the knowledge and the practice of engineering in the minds of the students. While the approach is not really new, it is part of the growing movement to reemphasize engineering practice. While the content of curricula, as well as the balance between theory and practice has dramatically changed over the decades, the predominant delivery method in most engineering schools today - the lecture - has remained static. In recent years, new findings in cognitive processes and behavioral psychology have demonstrated the limits of lecture, and alternatives to augment its effectiveness have been proposed, including laboratories and cooperative learning. The Learning Factory Concept was specifically designed and implemented to address these issues.

### The Manufacturing Engineering Educational Partnership; MEEP:

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 integration of engineering design and manufacturing, a common purpose, an unusual attitude of cooperation among the partners, and, lastly, the 1993 ARPA Technology Reinvestment Program (TRP) Solicitation

### 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 first objective will be the topic of this paper. A broader overview was presented by Lamancusa et. al. earlier this year [Reference (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
- Prepared and motivated for future learning.

The interdisciplinary curriculum, a Product Realization Minor (PRM), is now available as a degree option at the participating schools. Several departments at each school are cooperating in this development, including Mechanical, Industrial, Chemical, and Electrical Engineering, as well as Business. The curriculum consists of a progression of design and manufacturing courses, approximately one per term, allowing students to practice their engineering science fundamentals in the solution of real problems. The curriculum builds on current courses in graphics (CAD/CAM), design, and manufacturing processes. In examining the current curriculum we found it necessary to provide augmentation in several areas and we have developed the following new courses [see reference (1) for details]:.

- *Product Dissection*
- *Concurrent Engineering*
- *Technology-Based Entrepreneurship*
- *Process Quality Engineering:*
- *Interdisciplinary Senior Design Project*

Curriculum and laboratory development are time consuming and costly processes. Our mission is to jointly develop curriculum materials, in a modular and electronic format, 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.

**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 a controls laboratory. These laboratories are well defined in terms of their objectives, principles to be investigated, and skills to acquired.

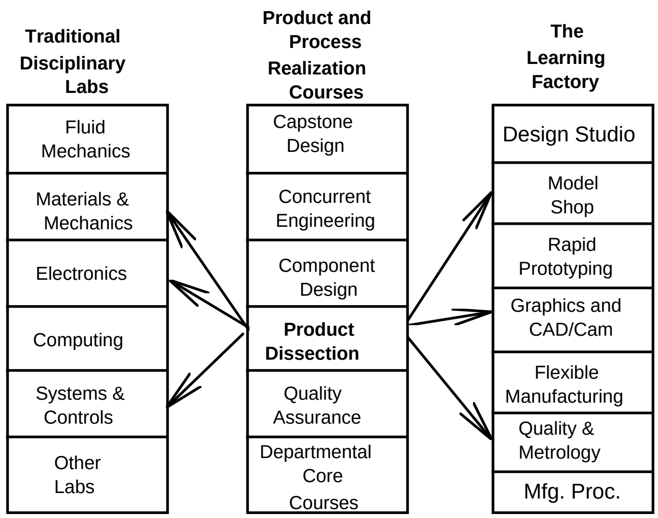


Figure 1 Relationship between Learning Factory, Product Realization Curriculum, and Traditional Laboratories

As illustrated in Figure 1, 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 Realization course uses Learning Factory facilities (model shop, design studio, CAD/CAM, Metrology, Mfg. Processes) as well as disciplinary labs (Electronics, Computing, Materials and Mechanics, Composites Processing).

In the Learning Factory, students are actively experiencing a product, or a process, realization in its entirety, from design concept, through rapid prototyping, to finished hardware. Typically, 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

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 represents regional difference based on local input and expertise. The basic implementation concept is shown in Figure 2. Here the Learning factory defined by the core activities necessary to support the course development and industrial interdisciplinary capstone design project activities. Surrounding the LF core are the existing and/or up-graded disciplinary and skill oriented laboratory facilities.

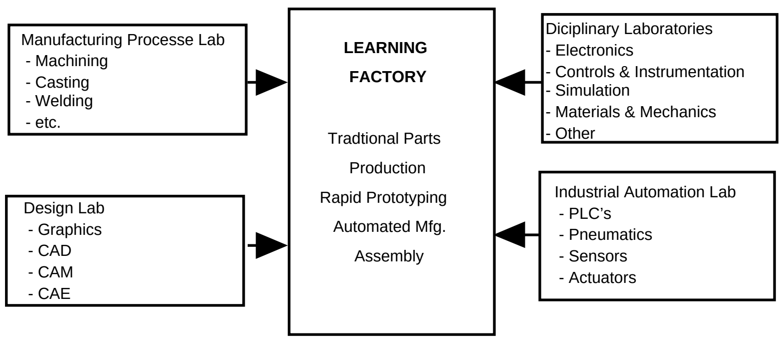


Figure 2    Learning Factory  Implementation Concept

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
- Ability to go from rapid prototype to finished product
- Model shop facilities, assembly and test, design studio
- Networked facilities at each institution
- Provide specialty services to the partnership

Figure 2 illustrates, in a generic manner, how we envisioned the integration of existing labs (Manufacturing process labs, Design, Automation etc.) into the LF concept. The added aspects of the Learning Factory became the ability to proved infrastructure and resources to courses and needs of the capstone design and entrepreneurship activities. At each of the MEEP institutions the Learning Factory "floor" received slight different implementation influenced by local industrial conditions:

### University of Puerto Rico @ Mayaguez

The core components of the UPRM Learning Factory will be a series of actual production lines that will produce real products (see figure 3). Other disciplinary 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. Our current line is now producing a family of desktop products make of tubes and sheets of PVC plastic cut to different sizes and shapes and assembled into the final products. The intention of this production line, designed and built by student/faculty teams, is primarily educational.

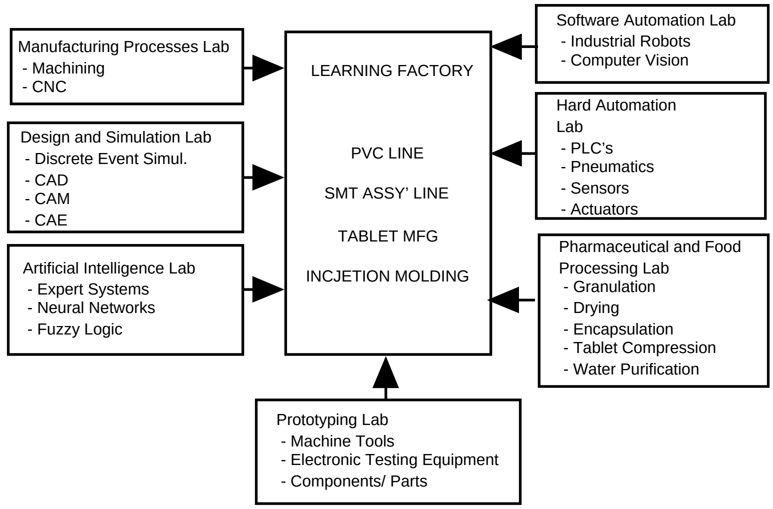


Figure 3: UPR-M Learning Factory and Supporting Labs.

It is expected that the production lines in the Learning Factory will be in 'dynamic of nature' as enhancements will be made to them and new products designed and produced. Each line is expected to have an useful life of about five to ten year after the initial implementation. In addition to the production lines can be employed to develop prototype manufacturing cells and training for local industry, or for new entrepreneurs.

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 include a surface mount technology (SMT) electronics assembly line currently under implementation and it is expected to be completed within the 1995/96 academic year. Next, is an injection molding line now under design and its projected completion is within the next two years. Lastly, a tablet manufacturing line is planned for a more distant future. These projects all have industry endorsement and sponsorship.

**Penn State University and the University of Washington**

The industrial community served by these two universities are diverse with respect to their products manufactured, manufacturing processes employed, 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 4).

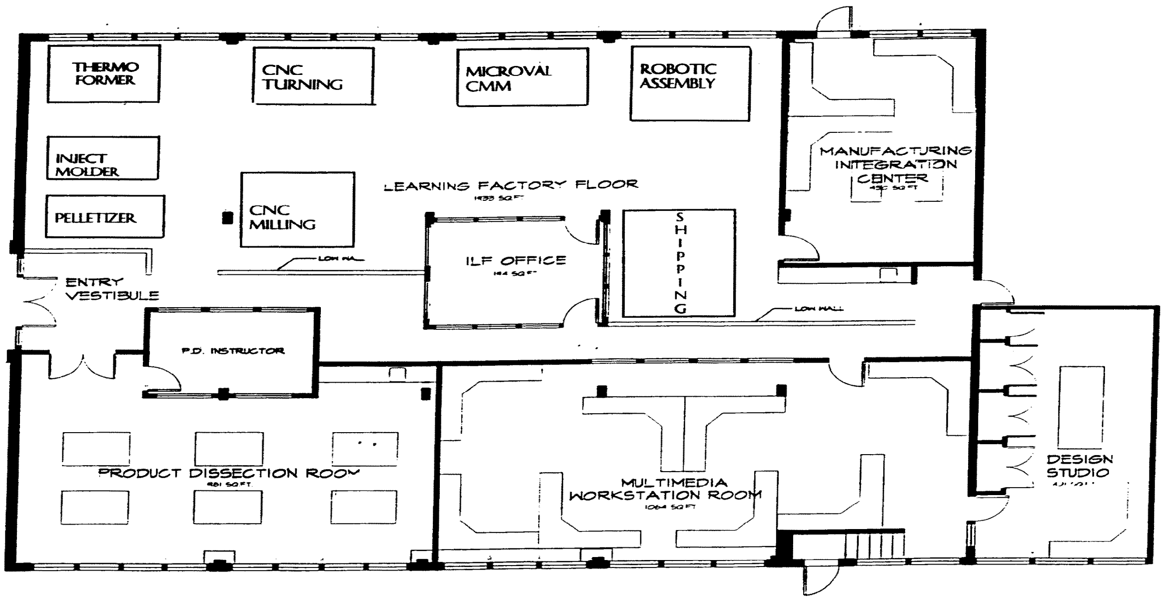


Figure 4 Learning Factory Layout at the University of Washington

The combination of design studio and multi-media facilities provide the students with support of workstations, printers and plotters, drafting tables, conference table, book shelves with design and manufacturing trade journals, suppliers catalogs, and the Thomas Register. The workstation are loaded 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 includes ability for rapid prototyping.

The product dissection room is a unique teaching 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 ant their integration into a product or system. Artifacts can be stored and retrieved for use as needed and the 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 (faculty) LF Coordinator (staff) and graduate teaching assistants. The directors responsibility is to coordinate facility usage with the teaching staff of teaching staff of the PRM courses. In addition, the functions of liaison with the industrial partners, seeking donations of capital equipment and materials as well as the continued 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 responsibility include the technical Administration of the LF, the 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 responsibility 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 and 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.

## IV. 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 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;
- 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.

## REFERENCES:

1 Lamancusa, John. S., Jens E. Jorgensen, Jose L. Zayas-Castro, and Julie Ratner. "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.