# The Learning Factory – 10 Years of Impact at Penn State


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***Abstract*** — *The Learning Factory at Penn State is a university-industry partnership established to integrate design, manufacturing and business realities into the engineering curriculum. This is accomplished by providing real (industry-driven) projects, a curriculum in Product Realization, and a state-of-the-art, hands-on learning laboratory. The Learning Factory began in 1994 as the result of a NSF/ARPA grant from the Technology Reinvestment Program. It has continued to grow and prosper long after the initial grant ended. In ten years of operation, the Learning Factory at Penn State has generated over $5M to support hands-on learning activities and projects, facilitated over 400 inter-disciplinary capstone design projects for 120 corporations and non-profit institutions, and provided real-world educational experiences for over 8,000 students. The fundamental innovations of the Learning Factory that have had the greatest impact at Penn State are:*

- ***Facilities:*** *The Learning Factory <http://www.lf.psu.edu> is an open-access, active learning laboratory, where students, faculty and industry from all disciplines can "roll up their sleeves" and practice real engineering. It provides practical training and modern facilities for design, prototyping, manufacturing, testing and re-design. These facilities support numerous student design projects and competitions, enabling faculty to integrate engineering practice into their courses.*
- ***Industry Interaction:*** *The Learning Factory provides an efficient infrastructure for actively involving industry in the educational process through capstone design projects, curriculum improvement, and engineers in the classroom.*
- ***Curriculum:*** *The Product Realization Minor comprises three elective courses that cover product dissection, concurrent engineering, and engineering entrepreneurship, in addition to required courses in manufacturing processes, quality control, and the capstone design course. The Minor averages ten students each year from IE, ME, EE, and Engr Sci and has served as the benchmark for several new minors within the College of Engineering, including minors in Leadership and Entrepreneurship.*

*In this paper, we present details of these successes along with lessons learned from our experiences.*



***Index Terms*** — *Capstone design, industrial collaboration, integrating engineering practice, multidisciplinary projects*


## BACKGROUND

Before World War II, hands-on learning was the norm. The post-war rise of the theoretical lecture and computer-simulated design moved undergraduates from the shop into chairs at desks and terminals. Campus labs were scattered and territorial by discipline. By the late 1980s, industry complained of graduates who required extensive training before they could put theory into practice. Faculty lamented a lack of experience solving design problems in a manufacturing environment. Brilliant students opted out of engineering majors for lack of hands-on opportunities to satisfy creativity, and graduates lacked communications and teamwork skills critical to business success. The National Science Foundation responded, asking universities to examine curricular alternatives. Penn State answered the challenge, by leading the University of Puerto Rico-Mayaguez (UPRM), the University of Washington and Sandia National Laboratories in a Manufacturing Engineering Education Partnership (MEEP). In 1995 the ARPA/NSF (Technology Reinvestment Program in Manufacturing Engineering Education) awarded the partnership $2.75M to build campus *Learning Factories* that would drive radical shifts in curricula: students would work in interdisciplinary teams to solve real-world design problems posed by manufacturing firms, mentored by faculty and industry partners. After 10 years, the Learning Factories at Penn State, University of Washington and the University of Puerto Rico-Mayaguez are self-sustaining with continuing financial support from industry. Penn State's Learning Factory is the focus in this paper.

## WHY IS THE LEARNING FACTORY NEEDED?

The primary stakeholders in the educational process—students, faculty, and industry—have diverse and often conflicting views. The following briefly summarizes the viewpoint of each stakeholder.

### The Industry Viewpoint

Industry wants to hire graduates with common sense, a positive work ethic, and excellent communication skills. They want engineers who can apply the fundamentals to get the job done on time, in a team, and within budget. They want professionals who are willing and able to learn on their own. In a recent survey by the National Association of Colleges and Employers (NACE), employers were asked to rate importance of candidate qualities and skills; the results are shown in Table 1 [1].

| Quality/Skill | Importance |
|---|---|
| Communication skills (verbal and written) | 4.8 |
| Honesty/integrity | 4.7 |
| Interpersonal skills (relates well to others) | 4.5 |
| Motivation/initiative | 4.5 |
| Strong work ethic | 4.5 |
| Teamwork skills (works well with others) | 4.5 |
| Analytical skills | 4.4 |
| Flexibility/adaptability | 4.3 |
| Computer skills | 4.1 |
| Detail oriented | 4.0 |
| Leadership skills | 4.0 |
| Organizational skills | 4.0 |
| Self-confidence | 4.0 |
| Friendly/outgoing personality | 3.8 |
| Tactfulness | 3.8 |
| Well mannered/polite | 3.8 |
| Creativity | 3.6 |
| GPA (3.0 or better) | 3.6 |
| Entrepreneurial skills/risk-taker | 3.2 |
| Sense of humor | 3.2 |

TABLE 1
THE TOP QUALITIES/SKILLS THAT EMPLOYERS LOOK FOR IN NEW GRADUATES (5=EXTREMELY IMPORTANT, 1=NOT IMPORTANT)

### The Faculty Viewpoint

It is interesting to note that what some faculty derisively refer to as “soft skills” (e.g., communication, interpersonal and team skills) are the most important to employers, but as noted in Table 1, analytical skills are seventh on industry’s list. Common faculty anecdotal views include:

- By the time they are seniors, students have no curiosity or creativity, and they do not want to learn.
- Students do not remember and cannot apply what I lectured about last semester.
- We do not have equipment or space to provide hands-on experiences.
- We need to teach students the fundamental theories and equations. They can learn the practical, non-technical material (“the other stuff”) on the job if they really need it.
- I am rewarded for being an independent researcher, technical author, and contract procurer, not an educator.
- I have no formal training in educational pedagogy.
- I never worked in industry
- I am not comfortable teaching non-technical, non-analytical topics – such as teamwork, creativity, project management, design, etc.

### The Student Viewpoint

Students are not highly motivated by sitting through passive lectures. They are crying out for hands-on experiences to complement the classroom lecture experience. Students need a place (analogous to a child’s *sand box*) away from the lecture hall, where they can get their hands dirty. They need a place where they can put the pieces of their education together in their own words, at their own pace and on their own terms.

After 10 years of operation, we are even more convinced that the traditional, lecture-based approach to engineering education is no longer sufficient. We need to augment lecture with hands-on practice in the art of engineering. The Learning Factory provides fills this void at Penn State. The mission of the Learning Factory is to integrate design, manufacturing and business realities into engineering education. This is accomplished by providing a state-of-the-art, hands-on active learning laboratory, a practice-based curriculum, and real (industry-driven) projects.

## ACTIVE LEARNING FACILITIES

The Learning Factory provides the "sand box" to inspire self-directed student exploration. To be most effective, we have found that this sand box should be highly accessible, multi-purpose, re-configurable, and not owned by a single department. This removes organizational barriers, maximizes the educational benefit and resource usage, and minimizes administrative costs. The sand box should be a common "melting pot", where diverse groups (students, faculty, industry) meet, interact, and learn from each other without departmental turf issues.

The Learning Factory at Penn State includes design studios, teaming and conference areas, and manufacturing facilities (see Figure 1). Together, these facilities encourage students to actively experience the product realization process in its entirety, from customer need and design concept to finished hardware. In the process, students can experience the following.

- Apply their theoretical knowledge to solve real problems
- Develop common sense and judgment
- Learn to work with persons of all motivational and educational levels and develop an appreciation for other disciplines
- Learn from their errors: *Good judgment comes from experience – experience comes from bad judgment*
- Discover that not every part designed in 256 gazillion colors on a CAD workstation can be built, nor will it work properly the first time
- Discover that everything takes longer and costs more than planned


FIGURE 1
THE LEARNING FACTORY'S MANUFACTURING SHOP ON A TYPICAL DAY

The facilities are open to any student, from any department, on a walk-in basis. The Learning Factory provides modern design, prototyping, and manufacturing facilities as well as expert supervision and training in their usage. Training classes are offered in safety, machining, welding and rapid prototyping. Capabilities include machining (CNC and manual), rapid prototyping, welding, assembly, and metrology (see Figure 2). Any engineering student can use the Learning Factory for a course-related activity. The shop is open 8 am-10pm M-F and on weekends as needed. Instructors can schedule all or part of the facilities for an organized class activity.


FIGURE 2
STUDENTS GAIN REAL MANUFACTURING EXPERIENCE BY WORKING IN THE LEARNING FACTORY

The Learning Factory is administered by the College of Engineering and is a resource for **all** engineering departments and units. It has a full-time staff, consisting of a director for overall administration and industry relations, a facilities coordinator to handle the day-to-day operations, several wage payroll teaching assistants, and two staff assistants for assisting students, budget administration, sponsor relations and event planning. Staff salaries are provided by the ME and IE departments, and the College of Engineering. Operating costs (materials, supplies, equipment, etc) are covered by overhead generated from industry project sponsorship fees, as well as corporate and benefactor support. Major financial donors over the past ten years include: Allied Signal, AT&T Foundation, Black & Decker, The Boeing Company, General Motors, Harold Johnson, Ingersoll-Rand, Kennametal, Lockheed Martin, and Microsoft.

## PRACTICE-BASED CURRICULUM

A key objective was to develop a practice-based engineering curriculum, balancing analytical and theoretical knowledge with design, manufacturing and business concerns. A strong collaboration with industry offers students and faculty real-world challenges. All courses require the practice of communications (written, oral, graphic) and team-building skills (training, coaching, leading problem-solving, active listening) required for industry success.

### Product Realization Minor

The Product Realization Minor comprises three elective courses that cover product dissection, concurrent engineering, and engineering entrepreneurship, in addition to required courses in manufacturing processes, quality control, and the capstone design course. The Product Dissection, Concurrent Engineering, and Entrepreneurship courses were developed by the Learning Factory team specifically for this purpose. The Engineering Entrepreneurship course focuses on the process of starting, financing, and managing a business as well as managing an existing enterprise. The course is designed for business and non-business students and is intended to provide a broad practice-based experience in the process of creating new products starting with idea generation and ending with plans for the commercialization of new products. The Concurrent Engineering course investigates engineering and management tools for concurrent product and manufacturing process development. The course uses case-studies from various industries to teach students about team dynamics, management of concurrent engineering projects, including the voice of the customer, and design for manufacturing and design for assembly methodologies. Finally, the Product Dissection course combines hands-on laboratory experience with lectures to 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. The dissection approach pioneered by the Product Dissection course has been adopted by several other courses across the college. A link to the Product Realization Minor is accessible from the Learning Factory web page <http://www.lf.psu.edu/>.

The Minor averages a dozen students each year from IE, ME, EE, and Engr Sci and has served as the benchmark for several new minors within the College of Engineering, including minors in Leadership and Entrepreneurship. Since 1998, 62 students have received the Product Realization Minor, of which 24 (39%) were women. The majority of the students (46) were from IE; the rest majored in ME (10), EE (4), and Engr Sci (2). The three elective courses that were developed as part of the Minor are over-enrolled each semester that they are offered. The Engineering Entrepreneurship course is by far the most popular due to its inclusion in several Minors within the College of Engineering, and enrollment controls have been placed on the course so that students enrolled in the Product Realization Minor get priority in the course.

**Senior Capstone Design**

The Learning Factory has put in place an infrastructure that makes it easy for all departments to implement industry-sponsored projects, and to actively involve industry in our curriculum. We take care of critical issues such as marketing, acquiring, managing, and assessing of student projects, as well as dealing with intellectual property issues. As a result of the umbrella organization and the facilities provided by the Learning Factory, the Mechanical, Industrial, Chemical, Computer Science and Engineering, Aerospace, and Electrical Engineering Departments at Penn State now collaborate on an industry project course each semester. This course is typically taken in the senior year and is the culmination, or "capstone", of the students' academic careers. The course requires students to demonstrate the ability to apply their rigorous training in engineering science, design and project management by executing a real-world project defined by an industrial client. Students work in inter-disciplinary teams. Sponsors contribute a nominal fee to cover project expenses and provide a project mentor. Over 400 projects, for 118 corporations and non-profit organizations have been completed since 1995, involving over 2000 students from Aerospace, Chemical, Electrical, Industrial, Mechanical, and Computer Science and Engineering. Most industry sponsors are repeat customers.

The capstone design course commences with a Project Kickoff at the beginning of each semester, where representatives from sponsoring companies "sell" their project(s) and answer student questions. Students then "bid" for their top three preferred projects, and then the instructors from the capstone design courses get together and assign students to each project accordingly. The culmination of the student teams' efforts is the Project Showcase, which takes place at the end of each semester (see Figure 3). This biennial event is the major exposition of student projects for the College of Engineering. It offers students the chance to "market their wares" and take justified pride in their accomplishments. Typically, more than 60 projects are displayed. Also included in the Project Showcase are design projects from the first-year design program, the entrepreneurship program, and the graduate program in Quality and Manufacturing Management (QMM). A competition for best capstone project is held, sponsored by Lockheed Martin. Winning teams are selected by a team of practicing engineers who serve as judges for the competition. Industry sponsors find the Project Showcase to be an excellent place to recruit new talent and to network with other companies.

FIGURE 3
TEAMS DISPLAYING THEIR PROJECTS IN THE PROJECT SHOWCASE

## IMPACT ON OTHER PROGRAMS AT PENN STATE

Internally, the Learning Factory has been a catalyst for curriculum innovation and new facilities at Penn State, including the Center for Engineering Design and Entrepreneurship (CEDE) and the Business Solutions Group of the School of IST (Information Science and Technology). The Learning Factory and its strong industry base have helped to dissolve some of the barriers between departments, inspiring new collaborations between the Aerospace, ME, IE, EE, CSE and ChE departments, as well as the School of Business. The best evidence of this is the multi-department capstone design course, where students working in inter-disciplinary teams solve real problems for industry. Other academic programs that depend heavily on the Learning Factory include the Master's Degree program in Quality in Manufacturing Management (QMM) as well as the Entrepreneurship Minor. The design studio provides a hands-on component for 17 different courses, and programs including the Women in Engineering and Minority Engineering Program.

Several student organizations regularly use the Learning Factory to execute design projects. These are typically voluntary (not part of credit bearing course), and are initiated and run by students for the best of reasons – to satisfy their curiosity, and to learn. These projects satisfy a thirst for real experience in our better students that is not quenched by the standard lecture-oriented curriculum. The projects include:

- SPIRIT Rocket – NASA student satellite design and launch: <http://spirit.ee.psu.edu>
- LionSat – University NanoSat Program: <http://www.courses.psu.edu/ee/lionsat/>
- SAE Formula Race Car – design, build and race a small Formula style race car: <http://www2.mne.psu.edu/sae/fsae/>
- DOE Future Truck – Hybrid Electric SUV conversion: <http://www.psuhev.org>
- ASCE – Steel Bridge competition: <http://www.engr.psu.edu/ASCE/Steel Bridge Webpage/>
- Mars Society – Martian surface rover competition: <http://www.clubs.psu.edu/up/mars/>
- Aerospace Engineering – Sailplane design and construction: <http://www.psu.edu/dept/aerospace/sailplane/>

Recent successes for student projects include:

- **SAE Formula Race Car –** best finish ever for PSU at the 2004 SAE international competition in Pontiac MI:
  - 6$^{th}$ place overall out of 130 entries
  - 2$^{nd}$ in acceleration,
  - 3$^{rd}$ in fuel economy,
  - 4$^{th}$ in endurance,
  - 4$^{th}$ in endurance,
  - 12$^{th}$ in design
- **DOE Future Truck –** highlights of DOE 2004 competition at Ford Proving Ground include:
  - 2$^{nd}$ place overall
  - Best Workmanship Award
  - Dr. Donald Streit Sportsmanship Award
  - Best Vehicle Design Inspection Award
  - Visteon Innovative Use of Electronics Award - 2nd place
  - The Mathworks Modeling Award - 2nd place
  - National Science Foundation Outstanding Faculty Advisor Award
- **SPIRIT Rocket -** The SPIRIT II payload launched successfully atop a NASA Nike-Orion rocket from Wallops Island, VA on October 3rd 2003. The rocket reached an apogee of 125 km and was successfully recovered from the Atlantic Ocean. The rocket's mission was to take wind measurements in the upper atmosphere in order to study atmospheric dynamics. The rocket had a total of five experiments: an integrated electron count, a direct current probe, a trimethyl aluminum chemical release, a chaff experiment and a GPS sphere.

## INDUSTRY INTERACTION

As a result of the Learning Factory, representatives from industry contribute to the students' education process in a number of ways. Guest lectures by practicing engineers in their field of expertise add excitement and reality to the classroom. Project sponsors provide invaluable mentoring to students (and faculty) in the technical and non-technical aspects of real-world projects. The Learning Factory's effectiveness and relevance are continually assessed and challenged by an Industry Advisory Board. This board, which consists of practicing engineers and mid-level managers, helps market the program to future project sponsors, provides curriculum and program feedback, and suggests improvements from the perspective of our industrial customers. A cumulative list of industry project sponsors is shown in Table 2.

## IMPACT BEYOND PENN STATE

Penn State's Learning Factory has been a model for similar programs, both nationally and internationally. It has been benchmarked by Rowan University, University of South Florida, York College, Carnegie Mellon, RIT, WPI, and Northeastern University. Our program has been presented at numerous national and international conferences and documented in 37 publications in proceedings and archival journals. A public web site <http://www.lf.psu.edu/> provides complete access to all course materials and publications.

Led by our sister institution, the University of Puerto Rico-Mayaguez (UPRM), the Learning Factory model has been widely disseminated. In 1998, UPRM received two dissemination grants from NSF's Engineering Education Action Agenda and Raytheon Company, which were later matched by Microsoft Research and more recently by Hewlett Packard. More than 35 workshops have been offered nationally and internationally to hundreds of faculty and deans, many whom have adopted or adapted this model. The workshops guide attendees through the steps that helped Penn State, UW and UPRM develop their programs. Outcomes assessment and accreditation strategies are also shared. This workshop has been offered at: 1998 & 1999 Frontiers in Education Conferences; 1999, 2000 ASEE Conferences; 2000 SUCCEED-GATEWAY Conference in Greensboro, NC; UTEP, Tennessee State University, Southern University, North Carolina A&T; 1999 ICEE Conference; Texas A&M - Prairie View; Polytechnic University - Puerto Rico; University of P.R. at Bayamón; Worcester Polytechnic Institute; 2000 ADMI Conference, Hampton University, VA; University of Chile; Pontifical Catholic University of Chile; University of Buenos Aires; Universidad Tecnológica Nacional, Argentina; and Universidade Estadual de Campinas, Brazil. The impact in some of these sites has been outstanding, the most noteworthy example being Chile, where the Engineering Deans Council sponsored nationwide workshops for more than 130 participants. This resulted in curricular reform supported by government grants in which the UPRM workshop leaders assisted faculty at the Universidad Federico Santa María in Valparaíso, Chile, Universidad de Bio-Bio, Chile, and the Universidad de la Frontera, Chile in their implementation efforts.

| | | |
|---|---|---|
| ABB | EPICS | Mascotech |
| ABMA | FCI Electronics | Mega Design Inc. |
| Accusort | FMC Technologies | Microsoft |
| Advanced Glassfiber Yarns | Food Service Solutions | Muncy Machine Tool |
| Agilent Technologies | General Cable | Murata Electronics |
| Air Products | General Electric | NextGen Aeronautics |
| Airwalk | Germantown International | New Pig |
| Allied Signal | Gichner Shelter Metals | News Printing Company |
| Armstrong World Industries | Goodrich Corporation | NIOSH |
| AMP | GKN Sinter Metals | Northrop Grumman |
| APC International | Hardinge | OGIP Brick Tile |
| Applied Research Laboratory | Hartell/Milton Roy | Oldcastle Precast Inc. |
| ARCCA | Hershey Foods | Osram Sylvania |
| ATL Echo Ultrasound | Hershey Medical Center | Piezo-Kinetics |
| Atotech | Hoffman Diamond Products | Pratt and Whitney |
| BAE Systems | Honda of America | PPG |
| Bausch and Lomb | IBM Endicott | Precision Components |
| Biotronx | Idea Aerospace | Proact |
| Boehringer Laboratories | Ingersoll-Rand | Rental Uniform Service |
| Boeing | Inno-Vent | RLW Inc. |
| B. Foster Company | Intuitive Control Systems | Sensus |
| Bobby Rahal Honda | Ivalo Lighting | Sikorsky |
| Cable Mfg. and Assy | JLG Industries | Spike's Club Caddy |
| Cannondale | Kahler Industries | Sony |
| Conair Franklin | Kawneer Company | Standard Steel |
| Case New Holland | Kellogg Company | Technology Assessment & Transfer |
| Chamberlain Manufacturing | Kennametal | Texaco |
| Corning | Keystone Powdered Metal | Trane |
| CCOR | Kimberly Clark | University Park Airport |
| CSM Industries | Kodak | TRW |
| CTS | Kronosport Inc. | USGS |
| Decorator Industries | Lear | U.S. Navy |
| Delphi Automotive | Learning Tek | Uticom |
| Dentsply | Lemco Tool Corporation | Videon |
| Dorma Door | Lockheed Martin | Visteon |
| Ecycle | Lutron | WAG-MYR |
| Endicott Interconnect | Matson Enterprises | Westinghouse |
| Energy Institute | Mauell | Windfall |

TABLE 2
PAST AND PRESENT PROJECT SPONSORS

## AWARDS

The Learning Factory has earned national recognition, including the Boeing Outstanding Educator Award and the Exemplary Program Award from the Corporate and Foundation Alliance. It has been featured in the *New York Times*, *ASEE Prism* magazine, and the *Journal of SMET Education*. Largely for his work on the Learning Factory, Prof. Lamancusa was honored with the *2004 ASEE Fred Merryfield Design Award*.

## LEARNING FACTORY ACCOMPLISHMENTS

Parts made in the Learning Factory have flown in space, sampled sediments at the bottom of the Gulf of Mexico, and generated hundreds of thousands of dollars of savings for corporate clients. In its first ten years, accomplishments of Penn State's Learning Factory include:

- Industry-sponsored senior design projects – In a typical year, over 60 projects are completed for a variety of paying clients. Over 400 projects, for 118 corporations and non-profit organizations have been completed since 1995, involving over 2000 in interdisciplinary teams.
- Product Realization Minor – a multidisciplinary minor, 62 graduates to date
- Project Showcase – twice yearly exhibition of student projects, and the major public exposition of the College of Engineering
- Industry Advisory Board – to oversee operations, provide guidance and promote continuous improvement
- Impact on Existing Courses – facilities are used by 20-30 different courses each year, in multiple departments
- Hands-on training classes – shop safety, power tools, machining, welding, attended by over 1200 students per year.
- Continuing External Support – over $5M of cash and in-kind support generated by the Learning Factory
- Student usage in a typical year –
    - Senior design projects teams in ME, IE, EE, CSE and Aero: 450 students
    - Design competition teams (FutureTruck, FormulaSAE, Steel Bridge, Sailplane, Spirit Rocket, etc): 80 students
    - Freshman design projects: 900 students
    - Training classes (safety, machining, welding): 1200 students
    - Design studio usage: 400 students

## SUMMARY

The major lesson we have learned in ten years (or perhaps re-learned) is that students need to practice engineering, while they are studying it. The fundamental innovations of the Learning Factory that have had the greatest impact at Penn State are:

- ***Facilities:*** an open-access, non-denominational, cost effective, active learning laboratory, where students, faculty and industry from all disciplines experience the realities of design, manufacturing and business practice;
- ***Industry Interaction:*** an efficient infrastructure for actively involving industry in the educational process through student design projects, curriculum improvement and engineers in the classroom; and
- ***Practice Based Curriculum:*** Bringing engineering practice and real-world examples into the engineering curriculum.

Thanks in large part to its success, plans are on the books in the College of Engineering for a new $65M, 250,000 sq. ft. building in which the Learning Factory will enjoy premiere placement.

## REFERENCES

[1] Mackes, M., "Trends in College Recruiting," *Ingersoll-Rand Recruiting Conference*, Bethlehem, PA, July 19, 2004.

[2] Morell, L., Lamancusa, J., Zayas-Castro, J., Jorgensen, J., "Making a Partnership work: Outcomes Assessment of the Manufacturing Engineering Education Partnership", *Journal of Engineering Education*, Vol. 87, No.5, 1998.

[3] Prince, M., "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education,* Vol. 93 No.3, July 2004, pp. 223-232.