# A Proven Model to Re-Engineer Engineering Education in Partnership with Industry

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**Abstract**

Engineering educators have been searching for models to reform the engineering curriculum to better respond to stakeholders' needs, especially those who hire engineers. Many attempts have been done around the world but with relatively little impact on the way engineering is taught. Like most higher education, the education process is focused more on the teacher than in the learner. This paper focuses on describing the Learning Factory model's key elements for successful revamping of engineering curricula to better respond to stakeholders' needs and complying with ABET's accreditation criteria. This active learning engineering curriculum innovation undertaken by Penn State University (PSU), University of Puerto Rico at Mayaguez (UPRM) and University of Washington (UW), in partnership with Sandia National Laboratories was recognized by the US National Academy of Engineering in 2006, granting the Bernard M. Gordon Award. The paper includes several cases in which the model has been adopted or adapted and proposes the development of two new curriculum options adopting the LF model: one in the area of IT and Sustainability, and the other with the newly launched HP Institute. Finally, the paper shares lessons learned as well as recommends essential roadmap/steps that can be considered when engaging in the task of curriculum innovation,

**Keywords:** curriculum innovation, hands-on learning, engineering education, industry partnership.

**Resumen**

Los educadores de Ingeniería han buscado modelos para reformar el currículo de ingeniería de manera que éste pueda responder mejor a las necesidades de los constituyentes, especialmente a los empleadores de ingenieros. Intentos de renovación alrededor del mundo han tenido poco o ningún efecto duradero en la manera cómo se enseña la ingeniería. Como la educación superior, el proceso de educación centra en el profesor más que en el alumno. Este escrito se enfoca en describir los elementos básicos del modelo del "Learning Factory" para renovar el currículo y responder mejor a las necesidades de los constituyentes de la educación, y cumplir con los requerimientos de la acreditación de ABET. Esta innovación curricular basada en el aprendizaje active desarrollada por la Universidad de Penn State (PSU), la Universidad de Puerto Rico en Mayagüez (UPRM) y la Universidad de Washington (UW), en colaboración con los Laboratorios Nacionales de EEUU, Sandia fue reconocida por la Academia Nacional de Ingeniería de los EEUU en el 2006 con el prestigioso premio Bernard M. Gordon. Este escrito también comparte ejemplos de otros programas que han adaptado o adoptado este modelo para innovar sus currículos de ingeniería y propone utilizar el modelo para desarrollar otras opciones atractivas para estudiantes de ingeniería y ciencias de computación: una, para integrar sostenibilidad y tecnologías de información (SustainIT) y la otra con la nueva iniciativa del HP Institute. Finalmente, el documento describe las lecciones aprendidas y recomienda algunos pasos esenciales a seguir para la innovación curricular.

**Keywords:** innovación curricular, enseñanza activa, educación de ingeniería, colaboración con industria.

## 1. INTRODUCTION

According to Zull (1), two causal factors are critical to creating learning, or changing the brain: 1) practice, when learners practice something, and, 2) emotion, when students are engaged and happy about the learning experience. This is what best describes the Learning Factory (2), an engineering curriculum innovation project that three universities (Penn State, University of Washington and University of Puerto Rico at Mayaguez) in partnership with the US Sandia National Laboratories, undertook in 1996. Motivated primarily by industry, their need for competent engineering professionals, the students' yearning for learning about engineering and its practice early on in the curriculum and the availability of resources for curriculum innovation in manufacturing from the NSF and DARPA, the three institutions engaged in a process to innovate the engineering curriculum to better respond to industry needs, integrating the development of engineering professional skills and the awareness of business constraints through a hands-on practice based activities with real industry projects.

The next sections will describe the Learning Factory model, its evolution at the three institutions that developed the concept, how others have and continue to adopt/adapt the model in their quest to better respond to their constituents, a new proposal for curriculum revamping for the sustainability age, lessons learned and some essentials steps that could be considered for curriculum re-engineering.

## 2. THE LEARNING FACTORY MODEL

> *Students learn better when they are intensely involved with their education. Collaborating with others in solving problems and similar active learning activities prepares students to deal with the messy, unscripted problems they will encounter daily, both during and after college."* US National Survey on Student Engagement, 2010

After extensive dialogue with three major stakeholders (namely, students, faculty and industry) the partner institutions were driven by a mission: to integrate design, manufacturing, and business realities into the engineering curriculum. But instead of starting from ground zero and developing an entire new curriculum (which could have taken much more time, effort and resources) the partners decided on an approach to integrate innovations into the existing traditional engineering curriculum. We thought this approach would be easier and faster to develop and implement (like a pilot), allow us to collect data on outcomes that would convince others of adapting best practices and engage in further developments as well as demonstrate the concept of stakeholders involvement in a practical, simple manner. Sometimes, it is more practical to take an existing wheel and steer it in the right direction than to invent a new one.

Thus, four major intertwined tasks were developed to accomplish the Learning Factory goals in 2 years:

1. Active learning facilities – for students' hands on experiences work
2. Practice based curriculum – a series of elective courses focused on product development and manufacturing with real life industry projects spanning the curriculum
3. Industry partnership – to contribute in curriculum and learning facilities development, provide projects and evaluate outcomes
4. Dissemination – share with others best practices in the development and implementation of the programs.

The Learning Factory Model is described in Figure 1. It basically comprises four key elements: 1) learning facilities integrated with hands on learning, 2) competency based curriculum, 3) industry collaboration, and, 4) outcomes assessment for continuous quality improvement.


**Figure 1. The Learning Factory Curriculum Model**

In summary, the specific innovations of the Learning Factory partnership were: active learning facilities, called Learning Factories, that provide experiential reinforcement of engineering science, and a realization of its limitations; strong collaborations with industry through advisory boards, engineers in the classroom, and industry-sponsored capstone design projects; practice-based engineering courses integrating analytical and theoretical knowledge with manufacturing, design, business concepts, and professional skills; and dissemination to other academic institutions (domestic and international), government and industry.

The Learning Factory established a paradigm shift to industry-partnered, interdisciplinary, real-world problem solving in engineering education. While the initial concept of the Learning Factories at PSU, UPRM and UW proved that high-quality hands-on educational experiences can be sustained, even at large universities, the concept has changed and evolved at each institution. This fact proves that no innovation is final and that change is the only constant for education as well as for all other human endeavours. Nevertheless, this program complies with the American Board for Engineering and Technology (ABET)'s learning outcomes accreditation criteria (3) as well as engineering education leaders like Smith, Shepard, Johnson and Johnson (4), Felder and Brent (5) and Wankat (6) refer to as successful classroom student learning.

## 3. EXAMPLES OF ADAPTATIONS OF THE LF MODEL

The Learning Factory has stimulated innovation in engineering education worldwide, particularly in Latin America. The program has continued to grow long after the federal funds expired. While the individual elements of the program may not be viewed as particularly novel, we were able to synthesize and package a successful educational program from tried and true ingredients, and make them work at a variety of institutions. Below the reader can scan some examples of how various institutions have adapted the model or one or several parts of it.

**3.1 Learning Factory at Penn State University –** the leading institution in developing the model, Penn State's most impressive long-time result of this program is the integration of multi-disciplinary industry based projects were integrated into the engineering curricula.

*"The most important and lasting innovation of the Learning Factory at Penn State has been to engage students on open-ended multi-disciplinary design projects for external customers. Through the facilities provided by the Learning Factory, the Mechanical, Industrial, Biomedical, Chemical, Computer Science and Engineering, Aerospace, and Electrical Engineering Departments at Penn State now collaborate on an industry project course each semester. Students work in multi-disciplinary teams with faculty and corporate mentors on real, open-ended problems. They practice their skills and develop common sense and judgment on a project defined by an external client. Sponsors provide a project mentor and contribute a nominal fee to cover project expenses. Sponsors have included a wide range of industrial clients as well as community service organizations provided through the Engineering Projects in Community Service program (EPICS) which originated at Purdue (7)".*

**3.2 UPRM Experiences**

**3.2.1 Remote Sensing/GIS option** (8) - in 1998, and to respond to multiple national and local industry needs for remote sensing and geological information systems (RS/GIS), UPRM's College of Engineering received a NASA grant [NCC5-340] to adapt the Learning Factory model to strengthen several science, math and engineering programs in these areas. In this case, the curriculum electives (for the RS/GIS) track involved 10 disciplines including various engineering programs and mathematics, biology, marine sciences and agricultural sciences and the hands on, active learning activities were provided through undergraduate research activities starting in the freshman year but involving graduate students as mentors. NASA recognized the success of this program in 2000 among all similar grants given in this agency's division.

**3.2.2 Continuous Improvement and ABET Strategy** (9) (10) - due to the success of the Learning Factory program which included systemic evaluation of learning outcomes, one of the authors (Lueny Morell) was designated to lead UPRM's College of Engineering ABET accreditation strategy under the new criteria that were to become effective in 2000. The new criteria included the systemic development of skills and competencies beyond technical knowledge and the implementation of a continuous improvement program. The Learning Factory's approach was adapted College-wide to: a) consult stakeholders, especially industry, on the graduating engineer's desired outcomes, b) road-mapping the learning activities through the curriculum to develop skills and competencies, and, c) designing an outcomes assessment strategy and continuous improvement plan. UPRM's CoE successfully accredited all of its programs under the new ABET criteria in 2002.

**3.2.3 Industrial Biotechnology Program** (11) - in 2001 one of the faculty members working in the RS/GIS curriculum and assisting the College of Engineering with ABET preparations, was appointed chairperson of the Industrial Biotechnology program, who completely revamped this important program for the Puerto Rican industry, evolving from pharma to biotech (more than 60% of the top seller medications sold in the world are manufactured in Puerto Rico). Various important changes made this multidisciplinary program to be recognized by industry and government officials: a) the establishment of a high level industry advisory board that included government representatives, b) the requirement of an industry internship for all students, b) the continuous education program focused on developing professionals for the biotech industry, and the extraordinary commitment of the university, Puerto Rico and US governments to support the expansion of laboratory, education and research facilities (over $26Million investment). These are evidence of a program that responds to the ecosystem economic development needs.

**3.3 Learning Factory around the World**

**3.3.1 Engineering for the Americas Initiative** (12)- early in 2001 a group of industry and academic leaders of the Americas discussed the possibility of bringing together the best practices of the Learning Factory to enhance engineering education as principal foundation of knowledge base economies for the Americas (with special focus on Latin America). Today hosted by the Organization of American States (OAS), the Engineering for the Americas Task Force is comprised of a set of industry, academia, multi-laterals and government entities who do volunteer work around two principal initiatives: a set of bottom-up actions based on pilot projects involving specific stakeholders of this process, and, a set of top down political actions by key organizations such as the OAS and the Pan-American Academy of Engineering. Two important multi-million dollar projects for the region are being implemented, supported by the Inter-American Development Bank and other stakeholders: an accreditation system for the greater Caribbean, and, the integration of entrepreneurship into the engineering curriculum in Chile, Argentina and Brazil.

**3.3.2 Learning Factory Model Workshops Around the World** (13) - for over a decade, more than 90 Learning Factory workshops have been offered around the world. Now called "Learning Ecosystems: Bridging the Gap Between How We Teach and the Practice of Engineering", these ½ day to 4-5 days long workshops are tailored for engineering faculty and engineering deans interested in renovating their engineering programs to better serve their country/region's needs. Faculty from related disciplines and graduate students interested in pursuing academic careers are also strongly encouraged to attend. Workshops provide a space and time for faculty and deans to learn about engineering education issues, effective teaching/learning and become aware of best practices so they can become more effective educators. The workshops describe the importance of bottoms-up innovations enhanced by top-down leadership support working in partnership with industry stakeholders and involve a combination of theory and practice with active learning throughout (practicing what's being preached). Attendees are expected to work in teams, share and interact with others. Although there is no formal mechanism to follow up with innovations engaged after the delivery of these workshops, we know of several institutions that have adapted one, several or many of the Learning Factory model dimensions and/or pursued accreditation by ABET successfully. Yet we know of two of institutions that are revamping their engineering curricula following the Learning Factory Model: the Universidad de Valparaíso in Valparaíso, Chile and Walchand College of Engineering (WCE) in Sangli, Maharashtra, India. These are described below.

**3.3.3 Universidad de Valparaíso, Chile** - Chile is now promoting competencies as foundation for curriculum innovation and the College of Engineering of the Universidad de Valparaíso found in the Learning Factory model the elements and the process they needed to start writing learning outcomes and engage in curriculum renovation based on those. They started the process in January 2012. Results are expected to be learned soon.

**3.3.4 Walchand College of Engineering (WCE), India** – A few years back, WCE became an autonomous college having control of its curricula. The leadership of the institution's aspirations are to have the College become a world class institution and offer the state of Maharashtra and India engineering graduates that possess not only the knowledge but also the skills and competencies needed to support the region and the country's economic development needs. In February 2012 WCE initiated a college-wide program to renovate its curricula and selected the Learning Factory model as its roadmap. An aggressive plan to turn around its curricula has been initiated and the entire faculty and administration are rapidly implementing the steps to, among other issues, 1) establish industry advisory boards in every discipline, 2) revamp the infrastructure for learning modernizing laboratories and classrooms, 3) revise the curriculum content vis a vis the best in the world, reducing the number of credit-hours significantly and including elective tracks to provide learning opportunities to students in areas of interest to the College (e.g., entrepreneurship), 4) provide faculty development and training in pedagogy and learning to focus on student learning rather than teaching centered, and 5) integrate a continuous quality improvement culture by measuring outcomes and aspiring to internationally recognized accreditation. Again, results of these revamping will be known in time.

**3.4 A New Curriculum Proposal**: **the Sustain-IT curriculum Track for Engineering** (14) - information technology (IT) forms a crucial foundation for designing, building and managing the Sustainable Cities of the future. A recent global survey of curricula that integrates the role of IT in designing, building and managing sustainable cities of the future showed nil results. Two authors of this paper are proposing adapting the Learning Factory model to develop yet another important track in the engineering curriculum: sustainability and IT. Multidisciplinary topics include traditional ecological engineering; life-cycle design; scalable and configurable resource microgrids; pervasive sensing infrastructure, aggregation and dashboards; knowledge discovery, data mining and visualization; and, policy based control and operation. By providing a series of guided electives, industry experiences and outcomes assessment, any engineering program may offer engineering, and/or computer science students the opportunity to specialize in the area of IT for Sustainability.

**3.5 The HP Institute** – Last Fall 2011, Hewlett Packard launched the HP Institute (www.hp.com/go/institute) "created to develop the precise skills businesses need to spur innovation". Through HP Institute program, HP develops a partnership with higher education institutions to offer courses and certifications related to HP technologies that add value to any student's portfolio of knowledge and skills in engineering and computer science disciplines. Given that the HP Institute courses are hands on and practice based, universities that choose to establish an HP Institute on Campus can develop a track or minor in these technologies adapting the LF model.

**3.6 Other Exemplary Approaches in the US** – Authors praise other examples of similar approaches, among them University of Colorado – Boulder's Integrated Teaching and Learning Laboratory (ITLL) established in 1995 and also recognized with the US National Academy Gordon Prize in 2008; Queen's University – Ontario Canada's Integrated Learning Center (ILC) created in 2004; and, Northwestern University's Ford Engineering Design Center established in 2004. All focus on providing hands-on activities with real life experience to engineering students.

## 4. ASSESSMENTS TO EVALUATE LF ACCOMPLISHMENTS

Proving an innovation has been successful is not an easy task. Approval must be shown from all of the stakeholders involved. This is the case of how those involved in developing this novel approach to engineering education perceived the outcomes achieved, as demonstrated by the results below, included in the final report to the National Science Foundation (1999):

Industry Partners

- 95% believe Learning Factory students would be more useful to their companies

Students

- 83% learn better from hands-on experience vs. lecture
- 80% feel more confident in their ability to teach themselves
- 78% feel more confident to solve real problems

Faculty

- 64% said they had a better experience with Learning Factory courses, compared to regular courses
- 57% believe that their participation was a positive element for awards and recognition

## 5. Lessons Learned

There are many challenges in the process of curriculum innovation and adapting the Learning Factory curriculum model. This is what we have learned from these experiences:

> **Leadership**: strong leadership from the top and faculty champions are needed to carry on the kinds of innovations we mention in this paper. That is, the approach has to occur both from tops down and from bottoms up.
>
> **Industry as a Partner**: Industry has to be involved in all phases of the innovation process, from sharing their needs in terms of content and skills and capacities of engineering graduates, to course and curriculum design, providing projects for students to finally providing resources and support.
>
> **Appropriate Environment to Stimulate Learning**: The right learning environment will motivate students to learn on their own. Personal experience on real problems develops skills and knowledge that are far more memorable and transferable than a passive lecture. In the words of Albert Einstein—"the only source of knowledge is experience". Facilities must be safe, multi-disciplinary, well-equipped, general purpose, welcoming, and visually impressive. All students, regardless of their major, should have open access. Economies of scale and the desirability for multi-disciplinary teams dictate that facilities should not be owned by a single department. Supervision and training in safe practices must be provided.
>
> **Outcomes Assessment and Faculty Buy-In:** collecting evidence on outcomes to learn and re-engineer innovations is critical. It is also important to convince others of the success and lessons learned to colleagues and industry.
>
> **Support and Resources**: Continued evolution and improvement of engineering education will depend on sustainable support from academic administrators, faculty, industrial partners and prominent national organizations such as the NSF and NAE.

## 6. Curriculum Innovation Steps (15)

> *"The object of education is to prepare the young to educate themselves throughout their lives."* ~Robert M Hutchins
>
> *"I do not teach anyone. I only provide them the environment where they can learn."* ~Albert Einstein

The LF team documented its process for curricula innovation and are now writing guidelines to help others in the task. Starting with a description of curriculum as "the set of experiences a student has to go through to acquire knowledge and develop skills", the authors recommend applying the engineering problem solving approach fundamental to curriculum innovation, which would entail the following essential steps:

- Curriculum innovation alignment with university, college and program strategic intentions
- Definition of program student learning objectives and desired outcomes (with input from stakeholders)
- Design the learning environment and learning experiences
- Measure results and make decisions to improve

- Share results with stakeholders

## 7. CONCLUSIONS

The Learning Factory model is a successful experiment which has demonstrated that a hands-on approach to engineering education is pedagogically sound, sustainable, cost effective and transferable. Adapting or adopting this model's elements of 1) learning facilities integrated with hands on learning, 2) competency based curriculum, 3) industry collaboration, and, 4) outcomes assessment for continuous quality improvement enhances the opportunities for engineering programs to better respond to their stakeholders' needs. This is demonstrated by the results achieved by the various institutions and initiatives highlighted in this paper as well as those who continue to select this model as their basis for innovation.

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