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

Lueny Morell, Martina Trucco

HP Laboratories
HPL-2012-128

Keyword(s):
curriculum innovation; IT; sustainability; engineering education

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, an 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 in 1998, an innovation that was recognized by the US National Academy of Engineering in 2006, granting the Bernard M. Gordon Award. This model seems to follow an education method that makes the learning experience effective for both students and professors and satisfactory to those who hire its graduates. In addition to describing the Learning Factory model, which complies with all of ABET criteria, the paper also shares examples of other programs that have adapted or adopted this approach to revamp their curricula. It will also present two proposals to develop new curriculum options: one in the area of IT and Sustainability, and the other with the newly launched HP Institute. Finally, the paper recommends an essential roadmap/steps that can be considered when engaging in the task of curriculum innovation.
A Proven Model to Re-Engineer Engineering Education in Partnership with Industry

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, an 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 in 1998, an innovation that was recognized by the US National Academy of Engineering in 2006, granting the Bernard M. Gordon Award. This model seems to follow an education method that makes the learning experience effective for both students and professors and satisfactory to those who hire its graduates. In addition to describing the Learning Factory model, which complies with all of ABET criteria, the paper also shares examples of other programs that have adapted or adopted this approach to revamp their curricula. It will also present two proposals to develop new curriculum options: one in the area of IT and Sustainability, and the other with the newly launched HP Institute. Finally, the paper recommends an 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 el modelo del “Learning Factory”, una innovación curricular basada en 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 en el 1998. El proyecto que fue reconocido por la Academia Nacional de Ingeniería de los EEUU en el 2006 con el prestigioso premio Bernard M. Gordon. Este modelo sigue un método de educación que logra que la experiencia educativa sea efectiva tanto para el estudiante como para el profesor y satisfactoria para los empleadores y los que reclutan ingenieros. En adición a describir el modelo del Learning Factory, que cumple con los requerimientos de la agencia acreditadora de programas de ingeniería de los EEUU, ABET, el documento también comparte ejemplos de otros programas que han adaptado o adoptado este modelo para innovar sus currículos de ingeniería. También presenta dos propuestas para desarrollar 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 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 model, that complies with ABET’s learning outcomes accreditation criteria (3), is better described by Figure 1. Learning facilities integrated with hands on set of one-theme elective courses and industry projects, the learning outcomes continuously assessed.
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.

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 **Remote Sensing/GIS option at UPRM** (4) - 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 Continuous Improvement and ABET Strategy at UPRM (5) (6) - 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.

3.3 Biotechnology Program at UPRM (7) - 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. Dr. Rosa Buxeda completely revamped this important program for the Puerto Rican industry (more than 60% of the top seller medications sold in the world are manufactured in Puerto Rico), which was evolving from pharma to biotech. 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.

3.4 Engineering for the Americas Initiative (8)- 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.

3.5 Learning Factory Model Workshops Around the World (9)- 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.

3.6 A New Curriculum Proposal: the Sustain-IT curriculum Track for Engineering (10) - 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. Figure 2 shows the Sustain-IT curriculum track model.

3.7 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.

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

Leadership and Strategic Planning: strong leadership and champions are needed to carry on the kinds of innovations we mention in this document. Their vision, mission and strategies need to be clearly outlined in a dynamic strategic plan that can provide a roadmap for the team leading innovations. The Strategic Plan also provides leadership to operationalize implementation as well as identify the metrics to be collected to understand if goals and objectives were met as well as providing evidence for strategies redirection. Strategic planning also includes following a series of essential steps (discussed in the next section).

Industry as a Partner: Industry should be involved in all phases of the education process (curriculum design, advisory board, project sponsors, visiting lectures, faculty experiences, financial support).

Active Learning: The right 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”.

Appropriate Environment to Stimulate Learning: 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.

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.

5. CURRICULUM INNOVATION STEPS (11)
“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 curriculum is just one of the university functions or elements that help achieve its mission. While other elements may be as important as curricula in helping achieve a university, college or program goals, one may conclude that curriculum is one of the most important academic endeavours. And as such, how curricula are developed, innovated or reformed to better respond to stakeholders’ needs are very important task for a university, college or program.

In formal education, a curriculum (plural curricula) is the set of courses, and their content, offered at a school or university. As an idea, curriculum stems from the Latin word for race course, referring to the course of deeds and experiences through which children grow and mature.
in becoming adults. In other words, the curriculum is 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

6. CONCLUSIONS
The Learning Factory is a successful experiment which has demonstrated that a hands-on approach to engineering education is pedagogically sound, sustainable, cost effective and transferable (12). Overall accomplishments for this program include: national and international impact via dozens of publications, over 80 dissemination workshops, and sparking the Engineer for the Americas Initiative and more and more engineering faculty changing the way they perceive their roles as educators.

References

3) www.abet.org. [Online]