The Learning Factory: Industry-Partnered Active Learning

JOHN S. LAMANCUSA
Department of Mechanical Engineering
Pennsylvania State University

JOSE L. ZAYAS
Department of Industrial Engineering
University of South Florida

ALLEN L. SOYSTER
Engineering Education and Centers Division
National Science Foundation

LUENY MORELL
University Relations
Hewlett Packard

JENS JORGENSEN
Department of Mechanical Engineering
University of Washington

ABSTRACT

On February 21, 2006, the National Academy of Engineering recognized the achievements of the Learning Factory with the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education. The co-founders were commended "for creating the Learning Factory, where multidisciplinary student teams develop engineering leadership skills by working with industry to solve real-world problems." This paper describes the origins, motivation, philosophy, and implementation of the Learning Factory.

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.

I. MOTIVATION FOR THE LEARNING FACTORY

Prior to 1950, the practical arts dominated engineering curricula. The emphasis was on producing graduates who could be immediately useful to industry. In addition to foundational studies in Physics and Calculus, students developed visualization and graphical skills on the drafting board. They acquired direct knowledge of materials in foundries, machine shops, and test laboratories. They took field trips to factories, chemical works, and power plants. Calculations were done on slide rules and required a "back-of-the-envelope" reality check. The results helped to develop a deeper conceptual and intuitive understanding of the behavior of systems and machines.

The publication of the Grinter Report (Grinter, 1956) and the launch of Sputnik in 1957 are widely acknowledged to have caused a major transformation of U.S. engineering education. The traditional engineering handbooks were discarded and engineering curricula became more abstract with an emphasis on calculus and science. Expanding enrollments and shrinking budgets made mass lectures more attractive, and hands-on labs less so. The availability of powerful computer simulation tools and low cost computers held out the false promise of "no prototypes." During this same period, there was a dramatic increase in federal funds available for research, without a commensurate expansion of infrastructure. As a result, many of the hands-on shops and traditional labs were re-assigned to research programs, or became generic computer labs. The combined effect of these influences was that students spent far less time "doing" engineering, and depended far more on the computer for even the most routine estimates.

On the occasion of the centennial of the American Society of Engineering Education (ASEE), Lawrence Grayson made the following observation (Grayson, 1993):

> . . . the 1960's were the "Golden Age" for research universities. Federal support for academic research more than quadrupled over a period of eight years . . . . The number of faculty involved in engineering research grew steadily, even as enrollments and degrees were stable. The physical plant of universities expanded as new research facilities were built to house laboratories, equipment, professors, and graduate students. Teaching of graduate and undergraduate classes became a smaller proportion of the

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professors' responsibilities as they "bought" research time from their schedules with research grant funds . . . . the de-emphasis in teaching was in direct opposition to what the Society had been advocating for over half a century—that more, rather than less, attention should be directed toward improving engineering teaching. Continually increasing government funding through the present has continued to skew the emphasis between teaching and research toward research.

Today, there is an evolving consensus that universities need to strike a better balance between engineering science and engineering practice. There is a strong interest in improving engineering education for a variety of reasons, some of which are described below.

Students Want to Do Engineering: Students yearn for direct, first-hand experiences; not a professor's narration of the textbook or powerpoint slides. Students lack the real life experiences needed to make sense of complex technical concepts. Compared to previous generations, far fewer have tinkered with cars or ham radios, or grew up on a farm. Lacking context, the professor's message, no matter how well intentioned or eloquently projected, has few physical foundations upon which to attach. The primary methods of teaching engineering include passive lectures and recipe labs that require little processing, emotional involvement or imagination on the students' part. In the desire to prepare students for every contingency that they may encounter in their careers, we run the risk of overwhelming them with facts on a superficial level, at the expense of deep understanding and transferance. Since it is not possible in four years to teach students everything they will need to know, the ability to acquire new knowledge is the most important outcome for a successful engineering career. The "doing of engineering" on meaningful problems, can motivate students to learn the difficult fundamentals, in ways that are remembered long after the semester is over.

Encouragement from NSF and NAE: Several studies in the 1980s, which culminated in the *1989 Belmont Conference on Imperatives in Undergraduate Engineering Education* (Willenbrock et al., 1989), prompted action by the National Science Foundation. The Engineering Education Coalitions program began in 1989 and represented an investment in excess of US$10M to fund six coalitions. Both Penn State and the University of Washington were members of the first of these, the ECSEL coalition. These coalitions continue to have a major impact in changing the culture in engineering education (Borrego, 2007; Coward et al., 2000). Perhaps their greatest (and least quantifiable) accomplishment has been to convince some faculty (including the authors) to devote their passion, creativity, and intellectual ardor to the scholarship of teaching. Further, the National Academy of Engineering (NAE) also recently weighed in with its report, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* (National Academy of Engineering, 2004). Among its recommendations, the NAE advocates that: the essence of engineering, the iterative process of designing, predicting performance, building and testing, should be taught from the earliest stages of the curriculum; research in engineering education should be a valued and rewarded; new standards for faculty qualifications, appointments, and professional growth should be developed, for example, to require experience as a practicing engineer; interdisciplinary learning should be part of the undergraduate environment; and students should be taught how to learn.

Industry Wants Change: Industry is one of the primary customers of the university. Those customers are constantly challenging academia to make curricula more relevant to professional practice. Most degree programs devote the bulk of their credit hours to engineering science fundamentals and do a better job of preparing students for graduate study than for industrial practice. However, the majority of students who receive a B.S. degree (over 80%) begin their professional careers in industry and do not pursue a graduate degree (Penn State, 2005). Industry depends on the ability to hire graduates with deep technical **and** broad professional skills. An influential voice in this regard is the Boeing Company, and its Desired Attributes of an Engineer. In addition to a good understanding of engineering science fundamentals, these attributes include: design and manufacturing processes, system perspective, understanding the context of engineering (including economics, history, environment, customer and societal needs), ethical standards, teamwork, critical and creative thinking, curiosity and a desire to learn for life (The Boeing Company, 2006). In a recent survey by the National Association of Colleges and Employers (Mackes, 2004), employers of engineers were asked to rate the importance of candidate qualities and skills. Professional and non-technical skills (e.g., communication, team, design, ethics, leadership, organization) were highly prized. Analytical skills, while important, ranked lower on the list of desired skills. According to Bernard Gordon, the founder and CEO of Analogic Corporation, and the impetus behind the Gordon Prize, "Engineering is an unforgiving and demanding environment and for students to succeed as engineers, they must go far beyond theories, simulations and exam-taking." (Gordon, 2007)

The Qualifications of the Professorate Are Not Optimized for Teaching: The availability of external funds for discipline-based research and the increased promotability of the "research professor" have changed the complexion of the engineering professoriate. A minority of engineering faculty are now registered as professional engineers or have practiced engineering in an industrial setting. In addition, few engineering faculty have explicit training in education. At all other levels (K-12), teachers are mandated to have formal certification, and are regularly required to demonstrate currency and proficiency in educational methods. In the words of Susan Ambrose (Ambrose, 2006), when it comes to teaching, most faculty members enter the academy as "well intentioned gifted amateurs." While there are many inducements for professors to develop funded research, there are few rewards, other than the Gordon Prize, for pursuing excellence as an educator. Because it is easier to measure research productivity than teaching quality, tenure-track faculty at many schools are counseled to be just adequate in the classroom, and to concentrate their efforts on writing grant proposals and papers. While it is often assumed that great researchers are also great teachers, most research shows that there is no correlation between effective teaching and effective research (Wankat and Oreovicz, 1993).

We Know More About Pedagogy: Fortunately, we know more today about the psychology of teaching and learning. Graduate degree programs in Engineering Education are beginning to appear at major schools such as Purdue and Virginia Tech. Journals on engineering education have increased the frequency, quality, and impact of engineering education research. Through research on learning styles (Felder et al., 2000), it is now generally accepted that students learn in a variety of ways, many of which may not match their professors' preferred ways of thinking or teaching. Numerous studies have demonstrated that active, collaborative, problem-based learning are superior to traditional lecture-based methods (Dym et al., 2005; Hake, 1998; Prince, 2004; Rosselli and Brophy, 2006; Smith et al., 2005). Reviews of nearly a hundred studies comparing lecturing with other methods (Bligh, 1971; Biggs, 1999) have found that: unsupervised reading is better than lecturing; lectures are quite ineffective for stimulating higher-order thinking; lectures cannot be relied on to inspire students; and the attention span of students in lecture can be maintained for about 10 to 15 minutes, after which learning drops off rapidly.

II. The Learning Factory Concept

Our response to these influences was to create Learning Factories dedicated to *industry-partnered, active learning*. The Learning Factory was founded on three beliefs: lecturing alone is not sufficient; students benefit from interactive hands-on experiences; and experiential, team-based learning involving student, faculty and industrial participation enriches the educational process and provides tangible benefits to all.

The Learning Factory began in 1994 with support from a three-year grant from the ARPA/NSF Technology Reinvestment Program in Manufacturing Engineering Education as a partnership of Penn State, the University of Puerto Rico-Mayagüez (UPRM), the University of Washington (UW), Sandia National Laboratories and 24 corporate partners. On-going operations are now fully supported by university and industry funds.

A. The Partners

The universities in this partnership represent a broad geographical, cultural, and philosophical spectrum. Penn State (PSU) is a large land grant university, 2nd in the U.S. in granting engineering baccalaureate degrees (1,319 in 2006) and 14th in research expenditures (US$118M) (American Society for Engineering Education, 2007). The major mission of the University of Puerto Rico-Mayagüez (UPRM) is undergraduate education and it is the largest Hispanic-serving university in the U.S. (606 engineering graduates in 2006). The University of Washington (UW) is a major research institution, 21st in the U.S. in research expenditures and 17th in engineering B.S. degrees granted with 731 graduates. With different strengths and expertise, this group was well positioned to demonstrate the merits of experiential learning in a variety of institutions.

The most important element of a successful enterprise is people. Allen Soyster, then head of Industrial Engineering at Penn State, was the administrative leader. His job was to keep the team on task, on schedule, and to assure that each of the universities delivered on its commitments. Jose Zayas (UPRM), Jens Jorgensen (UW), and John Lamancusa (PSU) were in charge of operations at their institutions, as well as being task leaders for the partnership. Lueny Morell from UPRM led the assessment and outreach efforts. The voice of industry was an integral component in the development and continued operations of the Learning Factory. Our initial group of 24 industry partners spanned a wide range, from small companies to Fortune 500 corporations, such as IBM, Boeing and Hewlett Packard. Over the years, this list has expanded to over 200 corporations who have validated the Learning Factory concept by contributing projects, resources, feedback, and jobs for our graduates.

B. Mission and Tasks

The team began by assessing the current status, best practices, and opportunities to improve engineering education. The voices of all major stakeholders were considered (i.e., industry, faculty, students). Tempered by a realistic assessment of the partners' collective and individual strengths, achievable goals were set, and the pathway to achieve those goals was formulated. Ultimately, the partners were united by a mission: *to integrate design, manufacturing, and business realities into the engineering curriculum*. This mission was accomplished through four major tasks.

1) Active Learning Facilities: Over 19,000 square feet of facilities were developed and dedicated to hands-on instruction of undergraduates across the partner universities. Each university established hands-on learning environments appropriate to their circumstances. Penn State's and UW's facilities evolved around machining and rapid prototyping, whereas UPRM developed highly specialized facilities for pharmaceutical and electronic manufacture. UPRM"s Learning Factory is now operated by the Industrial Engineering Department and offers a "for-profit" printed-circuit assembly line doing contract work. UW's facilities provide extensive prototyping, machining and design capabilities for the Mechanical Engineering Department. Penn State's Learning Factory is now self-sustaining and expanding, with support from industry and the College of Engineering.

2) 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. Course objectives were developed through a process of achieving consensus of the stakeholders—faculty, industry and students. All courses require practice of communications and team skills. All course materials are disseminated freely on the Web. New or re-engineered courses included:

- Product Dissection—Reverse engineering of products and processes, and examination of the societal considerations that determine success in the marketplace.
- Concurrent Engineering—Methods for product/process development, capturing customer requirements, insuring manufacturability and serviceability.
- Technology-based Entrepreneurship—Technology innovation coupled with business planning and development (also a

degree requirement for Minors in Entrepreneurship, and Engineering Leadership Development)

- Process Quality Engineering—Statistical methods for engineering process characterization and improvement, with an emphasis on application in a lab experience.
- Interdisciplinary Capstone Design—Teams of students from several engineering departments solve design challenges for paying corporate clients and community service organizations.

3) Industry Partnership: A key element in the success and sustainability of the Learning Factory has been the participation of Industry. 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 urgency and 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 improved by an Industry Advisory Board. This board consists mainly of practicing engineers and mid-level managers. It provides program guidance, curriculum feedback, markets the program to future project sponsors, and provides a direct link to the current practice of engineering.

The Learning Factory is a central point of contact for companies wishing to interact with the university. It provides an infrastructure that makes it easy for all academic departments to implement industry-sponsored projects, and to actively involve industry in their curricula. The Learning Factory handles critical administrative issues such as marketing, acquiring, managing, and assessing student projects, as well as dealing with intellectual property concerns.

4) Outreach: The Learning Factory team has offered over 50 domestic and international workshops since 1998. These workshops, supported by grants from NSF, Raytheon, Microsoft and Hewlett Packard, have been presented at minority-serving institutions, at U.S. professional conferences (ASEE, FIE, ICEE), and internationally in Argentina, Brazil, Chile, Czech Republic, Peru, Panama, Sweden, Turkey and Mexico. As a result of the Learning Factory workshop in Rio de Janeiro, Brazil in 1998 at the International Engineering Education Conference (ICEE), a group of engineering educators, industry representatives, accreditation bodies, NGOs and government agencies have developed the concept of the ***Engineer for the Americas*** (EFTA). This concept calls for increasing the quantity and quality of engineers in Latin America by innovating engineering education and establishing standards in accreditation, curriculum and degree equivalency throughout the western hemisphere. This initiative parallels the Bologna accord for Europe. EFTA aims to build technical capacity for the American continent to facilitate the attraction of foreign direct investment, stimulate small technology-based businesses by entrepreneurs, and create high-quality, high-salary employment in the region for socio-economic development (Scavarda do Carmo et al. 2006).

III. The Learning Factory in Practice

We next describe two different examples of the implementation of the Learning Factory concept.

A. The Pennsylvania State University

1) Administration and Operation: 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 administration and industry relations, a facility coordinator to handle operations, several teaching assistants, and two staff assistants for assisting students, budget administration, sponsor relations and event planning. Staff salaries are provided by the College of Engineering. Operating costs (materials, supplies, equipment, etc) are covered by industry project sponsorship fees, as well as corporate and benefactor support. Major financial donors over the past twelve years include: Allied Signal, AT&T Foundation, BAE Systems, Black & Decker, Boeing, Case New Holland, General Motors, Ingersoll-Rand, Kennam et al, Lockheed Martin, Microsoft, and Shell.

2) Industry Sponsored Projects: 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 multidisciplinary 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 (Coyle et al., 2005).

Examples of recent projects include a self-propelled playground vehicle for mobility-limited children, sponsored by a local physical therapist. An erstwhile entrepreneur (and amputee) wanted a collapsible crutch that would make airplane travel easier. The agricultural sciences department needed a portable display for county fairs to demonstrate how easily a farmer can be suffocated in a grain bin. Kellogg's asked an interdisciplinary team to recycle waste heat from their ovens that produce Pop Tarts. Ingersoll Rand reports hundreds of thousands of dollars of productivity improvements as a result of their sponsored projects.

In light of Penn State's location in a rural, non-industrial area, and the need for enough projects to support a large student population, a low fee was adopted (US$2,500 donation per project team). No promises are made of outcomes, other than students will give best effort. In addition to project results, sponsors gain the opportunity to evaluate and recruit new talent. Many students receive employment offers from their sponsors. Most sponsors are repeat customers. On follow-up surveys, 90 percent of project sponsors report that they are satisfied or highly satisfied with their project outcomes. On average, 60-80 projects are completed each year. Over 700 projects have been completed for more than 150 industry sponsors since 1994.

The capstone design course commences with a Project Kickoff at the beginning of each semester, where representatives from sponsoring companies market their projects and answer student questions. Students bid for their top five preferred projects. Instructors from the participating departments confer and form teams based on student preferences and the staffing requirements of the sponsor. The culmination of the student teams' efforts is the Project Showcase, which takes place at the end of each semester. This biennial event is the major exposition of student projects for the College of Engineering and is attended by hundreds of parents, faculty, sponsors, and university and K-12 students. Design Excellence awards are given, sponsored by Lockheed Martin. Winning teams are selected by a judging team of practicing engineers.

3) Facilities to Promote Active Learning: The Learning Factory provides modern design, prototyping, and manufacturing facilities as well as expert supervision and training in their usage. Facilities, occupying 6,500 square feet, include a machine shop, design and dissection studio, model shop, conference room, project work area, and CAD lab. Supervision is provided and advice is offered to get them started, but students build their own dreams, make their own mistakes, and learn from them. Training classes are offered in safety, machining, welding, CNC and rapid prototyping. Capabilities include machining (CNC and manual), waterjet cutting, rapid prototyping, sheet metal forming, welding, assembly, electronic test and measurement, and metrology. Any engineering student from any department can use the Learning Factory for a course-related activity. The shop is open 8 a.m. −10 p.m. Monday through Friday, and on weekends as needed. Instructors can schedule all or part of the facilities for an organized class activity.

The Learning Factory is home to several student organizations and their national design competition entries, such as the SPIRIT Rocket, SAE Formula Race Car, ChallengeX Hybrid Vehicle Conversion, ASCE Steel Bridge, and ASME's Human Powered Vehicle. In a typical day, a visitor might see a computer science student building a mobile robot, or mechanical and electrical engineers discussing the best way to construct an instrumented payload that will fly on a NASA rocket. A troop of Girl Scouts might be dissecting toasters, while an entrepreneur waits for her latest concept model to be completed on the rapid prototyping machine. The Learning Factory is a "melting pot" where everyone, including faculty, learns from each other. Its primary purpose is not to train machinists or welders. Its purpose is to sensitize future designers to the societal, organizational, technical and business realities of creating economically and socially viable hardware and process solutions to the problems of the twenty-first century.

B. University of Puerto Rico-Mayaguez (UPRM)

UPRM developed the Learning Factory laboratory to support the local manufacturing industry of Puerto Rico. The UPRM team developed a network of physical facilities having a central location in the Department of Industrial Engineering with emphasis in plastic molding and electronics. Another facility was implemented in the Department of Chemical Engineering with emphasis on pharmaceutical manufacturing. More specialized laboratories were implemented or upgraded in the Departments of Mechanical and Electrical Engineering to support aspects such as robotics and automation, manufacturing process, and prototyping. All interested faculty and students could access the facilities. As at Penn State, industrial support and participation was critical in the development and enhancement of the facilities.

UPRM's Learning Factory evolution demonstrates the role of the university in workforce and economic development. Enabled by significant industrial support, UPRM's Learning Factory evolved to a full-fledged electronics manufacturing facility. In 2002 Hewlett-Packard and other industrial partners made a significant upgrade to the facilities with the establishment of real-life state-of-the-art surface mount technology production line to provide services to local companies in the electronics sector. The facility is now known as the *UPRM Model Factory*, since it aims at providing students with an exemplary manufacturing experience in terms of quality, delivery, continuous improvement, and productivity (Resto et al., 2006). Students begin their experience by attending a Printed Circuit Assembly course and then are recruited to work in the factory for pay and academic credit. After the experience, students are expected to participate in internship opportunities at companies in the electronics sector. The UPRM Model Factory initiative is part of the Puerto Rico TechnoEconomic Corridor effort.

From its inception, the UPRM's Learning Factory team emphasized cross-disciplinary activities. The team included faculty from the Colleges of Engineering and Business Administration. Later, the team expanded to include faculty from the Colleges of Arts and Sciences and Agriculture. Interdisciplinary student teams worked on hands-on projects; moreover, it was possible to achieve vertical integration in the more advanced and specialized projects with undergraduate students collaborating with graduate students. An interdisciplinary faculty team mentored the students. At its peak in the mid-1990s, UPRM's team had more than twenty faculty members—spanning three colleges, Engineering, Business Administration, and Arts and Sciences—working in the various aspects of the implementation of the Learning Factory. The success and energy of the endeavor spread quickly across campus. As a result the Learning Factory curriculum served as model and benchmark to design and implement other multidisciplinary programs at UPRM. These include the NASA Remote Sensing/GIS (Buxeda et al., 2002) and Industrial Biotechnology programs. Both of these programs integrated critical elements in the Learning Factory model, namely, strategic planning, outcomes assessment, and faculty team development, ensuring stakeholders' ownership of process through a common vision and mission.

A successful and unforeseen legacy of the Learning Factory has been the development and implementation of an assessment strategy at UPRM's College of Engineering. UPRM's College of Engineering developed its ABET EC2000 strategy based on the Learning Factory experience. UPRM's ABET accreditation visit team commented: "The institution's systematic and innovative effort to introduce the culture of outcomes-based assessment to the College of Engineering community is especially noteworthy" (Sharma et al., 2003). As a result of these experiences, UPRM has expanded this quality assurance and outcomes assessment effort to the university level and has begun the process of qualifying for the Malcolm-Baldrige quality criteria.

IV. Conclusions

The Learning Factory is a paradigm shift to industry-partnered, interdisciplinary, real-world problem solving in engineering education. The Learning Factories at PSU, UPRM and UW have proven that high-quality hands-on educational experiences can be sustained, even at large universities. 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. Sometimes, it is more practical to take an existing wheel and steer it in the right direction than to invent a new one.

The lessons learned from these experiences include:

- 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 Facilities 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.

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 (Morell et al., 1998). Overall accomplishments for the three partner universities include: national and international impact via 40 publications, 50 dissemination workshops, and sparking the Engineer for the Americas Initiative; over 1,200 sponsored design projects completed; US$10M in external support; and more than 200 industry partners. To date, more than 10,000 students have benefitted from this program.

Our recommendations for further improvement of engineering education include:

- Better rewards are needed for teaching excellence. We must unambiguously demonstrate to our faculty that quality teaching is of central importance to accomplishing our missions as institutions of higher learning.
- Faculty must add technical, professional, and human value beyond what is printed in their textbooks. This added value can derive from industry experience or research accomplishment, and both should be well represented in a typical department. Both should be comparably prized in hiring and promotion decisions.
- More (if not all) engineering faculty should have formal training in education, in addition to deep technical expertise. Continued professional development in the craft of teaching should be readily available, and highly encouraged. This in turn will drive continuous and systemic improvements based on sound educational principles and practice.

In closing, we would like to thank the National Academy of Engineering for honoring us with the Gordon Prize. We will do our utmost to justify the faith shown in us, by continuing our quest to improve engineering education, through industry-partnered active learning.

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Authors' Biographies

John S. Lamancusa is a professor of Mechanical Engineering and director of the Learning Factory at The Pennsylvania State University. Before coming to Penn State in 1984, he was employed at AT&T Bell Laboratories. Dr. Lamancusa is a research fellow of the Humboldt Foundation, a member of American Society of Mechanical Engineers, a fellow of the American Society for Engineering Education (ASEE), and a registered professional engineer. Dr. Lamancusa received his B.S. in Mechanical Engineering from the University of Dayton and his Ph.D. in Mechanical Engineering, with a minor in Electrical and Computer Engineering, from the University of Wisconsin-Madison.

Address: 329 Leonhard Building, Penn State, University Park, PA 16802; telephone: (+1) 814.863.3350; e-mail: jsl3@psu.edu.

Jens E. Jorgensen, now professor emeritus of Mechanical Engineering at the University of Washington, was director of the Learning Factory there until his retirement in 2000. He was the Boeing Professor of Manufacturing and has several patents. Professor Jorgensen's research has been focused on system dynamics, controls, and instrumentation related to automated assembly and manufacturing processes. Professor Jorgensen earned his B.S., M.S., and Sc.D. in Mechanical Engineering from the Massachusetts Institute of Technology.

Lueny Morell is director of university relations for Latin America for Hewlett Packard (HP) Company. She is responsible for developing and strengthening HP's ties to a select number of institutions in Latin America. She is involved in curriculum development, advising industry, facilitating accreditation initiatives, supporting student and faculty research, and philanthropic projects. Before joining HP in 2002, Professor Morell had a distinguished 24-year career at the University of Puerto Rico, where she held various positions, both at the Mayaguez Campus (UPRM) and the system level. She is a licensed professional engineer and a certified ABET evaluator.

Address: Hewlett-Packard Company, Highway 110 N Km 5.1, Bldg 2, ms HR, Aguadilla, PR 00605; telephone: (+1) 787.819.7418; e-mail: lueny.morell@hp.com

Allen L. Soyster is currently the director of the Engineering Education and Centers Division of the National Science Foundation. Previously, he was professor and dean of the College of Engineering at Northeastern University. From 1981 to 1996, he was professor and head of the Industrial Engineering Department at Pennsylvania State University. In 1988, Dr. Soyster was named a Fellow of the Institute of Industrial Engineers (IIE). He earned a B.S. in industrial engineering from Pennsylvania State University, a M.S. in Industrial Engineering and Operations Research from Cornell University, and a Ph.D. in Operations Research from Carnegie Mellon University.

Address: 4201 Wilson Boulevard, Room 585N, Arlington, VA 22230; telephone: (+1) 703.292.5346; e-mail: asoyster@nsf.gov

Jose Zayas-Castro earned his B.S. in Industrial Engineering from the University of Puerto Rico-Mayaguez (UPRM),and his M.S. in Industrial and Management Engineering, M.B.A., and Ph.D. in Management from Rensselaer Polytechnic Institute. He is currently professor and chair of the Department of Industrial Management Systems Engineering at the University of South Florida (USF). Previously, he held teaching and leadership positions at the University of Puerto Rico-Mayaguez and University of Missouri-Columbia. Dr. Zayas-Castro is a Fellow Award of the Institute of Industrial Engineers (IIE).

Address: 4202 E. Fowler Ave, Room ENC2403, Tampa Fl 33620; telephone: (+1) 813.974.2269; e-mail: josezaya@eng.usf.edu