AC 2011-683: INTEGRATING PROFESSIONAL PRACTICE INTO THE ENGINEERING CURRICULUM: A PROPOSED MODEL AND PROTOTYPE CASE WITH AN INDUSTRY PARTNER

Richard T. Schoephoerster, University of Texas at El Paso

Dr. Schoephoerster is the Dean of the College of Engineering at the University of Texas at El Paso, where he leads a College of over 3000 students (including approximately 500 graduate students) in 17 different BS, MS, and PhD degree programs, and 80 faculty members in six different departments with approximately $25 million in research funding from local, state, and national agencies and companies.

Dr. Schoephoerster received his B.S. in Biomedical Engineering in 1985, and his M.S. (1986) and Ph.D. (1989) in Mechanical Engineering, all from the University of Iowa. In 2008 he was elected a Fellow of the American Institute of Medical and Biological Engineering.

Ryan Wicker, University of Texas, El Paso

Ryan Wicker, Ph.D., is a Professor of Mechanical Engineering and Director and Founder of the W.M. Keck Center for 3D Innovation at the University of Texas at El Paso where he also holds the endowed Mr. and Mrs. MacIntosh Murchison Chair I in Engineering. Dr. Wicker received degrees from The University of Texas at Austin (B.S. in Mechanical Engineering with Highest Honors, 1987) and Stanford University (M.S. and Ph.D. in M.E., 1991 and 1994, respectively). Dr. Wicker worked in industry as an Engineering Thermodynamic Analyst with General Dynamics Fort Worth Division (1987-1989), and has spent his entire academic career at The University of Texas at El Paso (Assistant Professor, 1994-2000; Associate Professor, 2000-2005; Professor, 2005-present).

Ricardo Pineda, University of Texas, El Paso

Dr. Ricardo L. Pineda holds Ph.D. and M.Sc. degrees from Lehigh University and a B.Sc. degree from Universidad Nacional de Colombia. He has over 25 years of experience in Systems Engineering in different industries ranging from Research and Development at Bell Labs to Chief Technology Officer at AT&T in Mexico. He was a Distinguished Member of the Technical Staff (DMTS) at Bell labs where as a Systems Engineer he worked on requirements and the architecture of new services and technologies used in the AT&T Network. He was the Chief Technology Officer for the definition, development, implementation and deployment of the AT&T Services and Network in Mexico. He was also Siemens Business Services (SBS) Practice Director for Latin America where he was the main consultant in systems implementations in Venezuela, Colombia, Ecuador and Brazil. Dr. Pineda has extensive experience in Academia; he was a Professor at ITESM in Monterrey, Mexico and at the ”Universidad de Los Andes” in Colombia and currently at the University of Texas at El Paso. His current Research projects include: PI for ”Energy Security Microgrid Large Scale Energy Storage (LSES)” for Raytheon-Energy Solutions, PI for ”Prognosis & Resilience Design for Complex SoS” with Raytheon-IDS, PI ”SOS Global Attributes to Design Space Mapping” and ”Technology Refreshment Assessment Model” for LMC-Aero, and PI for the ”TMAC El Paso del Norte-Region” for the MEP program sponsored by NIST. Dr. Pineda was nominated by AT&T Bell Labs to receive the ”US-Hispanic Engineer of the year Award”, received the ”AT&T Architecture Award” and has received the ”Baldwin Fellowship” and ”Gotshall Fellowship” awards. Currently he is at the University of Texas at El Paso (UTEP) where he is the Systems Engineering Program Director, the Director of the Research Institute for Manufacturing and Engineering Systems (RIMES) and the Chair of the Industrial, Manufacturing and Systems Engineering Department. He is a member of INCOSE, IEEE, IIE, ASEE and ISACA.

Ahsan Choudhuri, University of Texas El Paso

Dr. Ahsan Choudhuri is Associate Professor and Chair of the Mechanical Engineering Department and Director of the UTEP NASA Center for Space Exploration and Technology Research (cSETR). Dr. Choudhuri's primary research interests are in aerospace systems and energy engineering. He received his degrees from School of Aerospace and Mechanical Engineering at the University of Oklahoma (MS, 1997, PhD, 2000) and Department of Mechanical Engineering at Khulna University of Engineering and Technology (BSc Engg, 1993).

Integrating Professional Practice into the Engineering Curriculum: A Proposed Model and Prototype Case with an Industry Partner

Abstract

We present a case for a dramatic shift in the university-industry relationship for engineering programs, following recommendations from two 2008 reports on the future of engineering education. The Carnegie Foundation for the Advancement of Teaching report[1] *Educating Engineers: Designing for the Future of the Field* established the "imperative for teaching for professional practice" in engineering education by providing the "engineering equivalent of the clinical dimension of medical preparation" that includes a "place to explore professional practice", not unlike the clinical sites utilized for the preparation of physicians. Dr. James Duderstadt's report[2] *Engineering for a Changing World* recommends the establishment of "graduate professional schools of engineering that would offer practice-based degrees at the post-baccalaureate level as the entry degree into the engineering profession," again using the training of physicians as an appropriate model. He also recommends the formation of "Discovery-Innovation Institutes," academia-industry-government partnerships for engineering, a cross between academic medical centers where education, research, and practice are synergistically united within one unit, and corporate R&D laboratories that link fundamental discoveries to innovative products and services through applied research.

To meet these recommendations, we propose the transition of engineering education to a medical center model that includes the following key elements:

- Clinical Experiences at the Post-Baccalaureate Level
- Incorporation of Clinical Experiences into Program Learning Outcomes
- Appropriate Mix of Research and Clinical Faculty
- Industry Ownership of Professional Practice Training
- Clinical Sites – industry practice based laboratories, internships, and collaborative research

We have initiated the first step toward development of a medical center-type model by establishing a prototype for the practice-based education of engineers through a partnership with Lockheed Martin Aeronautics Company. This paper describes the partnership initiatives aligned with the key success factors listed above. With this successful prototype case in hand, we are replicating this model with multiple companies, large and small, and across a variety of professionally-oriented Master's degree programs in the College.

We believe that the medical center model for engineering education and research will provide an optimal means to educate and train engineering students for preparation as effective professional engineers. As designed, this well-integrated cooperative approach for university-industry partnerships also promotes innovation, commercialization, and economic development.

Introduction

There is an increasing demand from industry, and a responsive desire by academics, to provide more professional practice skills and experiences to BS graduates of engineering programs. This is actually not a new phenomenon, as engineering programs have changed emphasis from practical training to theory and research often over the past 100 or more years. We are at a time now, however, when global competitiveness in innovation combined with an ever increasing knowledge base and complexity of the problems we as engineers face, is driving the need for an effective balance between theory and practice in the engineering curriculum.

The methods of providing practical training to engineering students has also varied over the years, but usually includes hands-on laboratory and shop (design-build) experiences, along with internships and co-operative educational opportunities in industry. Indeed, because of the strong applications orientation of the field, there has always been a vibrant and active link between academic engineering programs and industry. However, this relationship is most often kept at arm's length, from the academic viewpoint, in a somewhat delicate attempt to keep from "tarnishing" the academic standing of the discipline by excessive influence by industry. On the other hand, engineering-related corporations and government agencies have yet to fully incorporate into their business model a close relationship with academia for the purpose of training engineers, at least certainly not to the extent of, for example, the medical practice industry.

The purpose of this paper is to present a case for a dramatic shift in the university-industry relationship for engineering programs. An elevated level of interaction between engineering programs and industry has potential benefits that are multiple: 1) engineering students gain valuable practical experience while in school so that companies that hire them need to invest fewer resources in on-the-job training, 2) teaching and research by faculty are enhanced by industry relevance, and 3) the innovation engine of companies is aided by academic research. The model presented in this paper is similar to academic university medical centers, where education, practice, and research are tightly entwined, physically, administratively, and financially. The engineering model will by necessity need to be less integrated, and so this paper presents examples that aim to achieve similar outcomes (as the medical center model) within those constraints.

Evolution of Professional Practice Experiences in Engineering Programs

Engineering as a profession has always been designed to be responsive to societal needs. Beginning with military engineering and then quickly followed by civil engineering, engineers made the Roman Empire the powerhouse that it was. Following the establishment of West Point with a focus on civil engineering in 1802, engineering education in the US constantly evolved according to government and industry demand. Agriculture, the mechanical arts, and manufacturing dominated the 19th century needs, resulting in the development of shop courses where students gained hands-on experience with machine tools for farming and manufacturing.[1] With the rise of electrical engineering in the early 1900's, combined with increasing promotion of a scientific approach to practice and the desire to "professionalize"[1] engineering and establish it as a credible academic discipline, laboratory experience became the norm for practical experiences within the engineering curriculum.

The first internship or cooperative educational program began at the University of Cincinnati in 1906.[3] Its benefits over shop or laboratory experiences were clear: students could gain practical experience while earning a paycheck and networking with potential future employers. The model at Cincinnati eventually caught on, and cooperative education proliferated at engineering programs around the country over the following decades. Now, almost every engineering program in the U.S. offers cooperative education, but its role within the curriculum varies widely. For some engineering programs, cooperative education is a required, significant portion of the curriculum (Northeastern University for example), while at many universities it is a seldom-used option for students.

ABET's Criteria for Accrediting Engineering Programs[4] does not explicitly require internship or cooperative educational experiences. The general criteria mandate a "culminating design experience" that includes application of science and engineering principles with "engineering standards" and "realistic constraints." However, this requirement is most often met via an in-house design project that may or may not involve industry professionals. It is quite unusual, if not rare, if any of the ABET designated program learning outcomes are actually expected to be derived from internship experiences by students. In fact, it may be the lack of academic rigor in cooperative education programs that relegate them to the margins of typical engineering curriculum.[5]

The demands of the 21st century workplace, including globalization, ever-changing technology, and the increasing need for on-the-job training, has caused a resurgence in the interest and relevance of cooperative education in the last decade.[6] This resurgence in interest has also come with a desire to design the cooperative educational experience with *learning* at the forefront, as opposed to networking and increasing job opportunities. In 2007, the Carnegie Foundation for the Advancement of Teaching issued a study to examine the current state of preparation for the engineering profession.[1] The "imperative for teaching for *professional practice* (italics added)" emerged as a primary recommendation from this study. This study describes the importance of practical experiences as a means to guide the learner through a "cognitive apprenticeship" from novice to competent practitioner. Two of their primary recommendations for designing the engineering curriculum of the future were 1) providing a "professional spine" that supports the entire length of the program, what they term the "engineering equivalent of the clinical dimension of medical preparation," and 2) provide a "place to explore professional practice." The Carnegie study recommends a new emphasis on the traditional shop (design and build) and laboratory experiences as examples of "places" for professional practice experience.

Closing the University-Industry Gap: The Case for Innovation and Global Competitiveness

In his revolutionary book, Innovation Nation,[7] John Kao describes the dire state of the nation's innovation advantage and recommends the creation of "Innovation Hubs" to reestablish that global leadership. Innovation Hubs are characterized by active partnership between universities and their community stakeholders, including government and economic development agencies, along with the local small, medium, and large technology-based business enterprises clustered around a common theme appropriate to the region. By necessity, these hubs must be located in urban settings. 85% of all jobs in the US are located in urban cores and metropolitan areas, and 75% of the nation's GDP is derived from the top 100 U.S. metropolitan areas.[8] These facts place public urban universities at the turn of the 21st century in the former role of land-grant and flagship universities at the turn of the 20th century.

The late 19th century Morrill Land-Grant Colleges Acts had the following goals: 1) education for the "common man", most of who lived in rural areas; and 2) economic development by technology generation for the economy of the day – agriculture. These acts resulted in the establishment of land-grant universities that emphasized agriculture and the mechanical arts, in each of the 50 states.[9] In many cases these universities became what are now termed "flagship" universities for the state. In other cases, the states created a second "flagship" university that emphasized classical education and other professions (e.g., medical).[10] In the 100+ years since the establishment of these universities, the land-grant and flagships have evolved in two significant ways: 1) the decision by the federal government to outsource basic research to universities has transformed the flagships into national research universities with large basic research portfolios, and 2) as the percentage of the population who aspire to obtain a college education continues to increase, many of the flagships are now at full capacity (and beyond in some cases) to the point that only the top 5-10% of high school graduates can compete for admission.[9]

As opposed to the rural, agriculture based economy of the 19th century, the 21st century now finds us with a knowledge based economy and a population heavily based in urban settings. So the urban public institution is now required to accomplish the original purpose of the 19th century land-grant institution: 1) educating the common man and woman, most of whom are living in urban cities and a large proportion are from under-represented racial and ethnic groups; and 2) collectively driving the national economy by each university having a major impact on its regional economy. So the public urban university appears to be the ideal location for a new model of engineering education that more optimally prepares graduates for professional practice through highly integrated university-industry-government partnerships.

A Proposed Model for Professional Practice in Engineering Education

U.S. technological superiority in the 20th century was driven by major innovations brought about by industrial R&D laboratories, which focused on market-specific applied research to create new end-user applications based on fundamental technologies also developed in these labs through basic research. Meanwhile, academic laboratories focused primarily on basic research heavily funded by federal agencies. Prime examples of industrial labs were AT&T Bell Labs, Xerox Palo Alto Labs, and IBM Watson Research Labs. Today's rapid technology changes and globalization have caused a paradigm shift that has forced the above mentioned labs to re-structure their development and in some cases to outsource the research to universities. The best R&D practices for new product development and integration were lost in the transition, causing a threat to the maintenance of this country's competitive advantage in the global marketplace. In his recently released report *Engineering for a Changing World*,[2] Dr. James Duderstadt, former

Dean of Engineering and President of the University of Michigan, has proposed a new paradigm to replace the now extinct industry R&D laboratories as the innovation drivers for the nation: "Campus based research centers … miniature Bell Laboratories, capable of conducting the long-term research necessary to convert basic scientific discoveries into the innovative products, processes, services, and systems needed to sustain national prosperity and security in an increasingly competitive world." Duderstadt called these centers Discovery-Innovation Institutes (DII). The DIIs are characterized by academia-industry-government partnerships, are interdisciplinary in nature but focused on a specific area of research such as energy, and will drive the engineering education enterprise within the institution. Duderstadt describes the DIIs as a cross between corporate R&D laboratories (linking fundamental discoveries to innovative products and services through applied research), agricultural experiment centers and extension services (like land-grant universities, responding to societal needs), and academic medical centers (uniting education, research, and practice within one unit). Therefore, DIIs will involve very active university-industry-government collaboration for practice-based education of engineers (like medical schools do for physicians), and for joint research and development activities.

We are in the process of developing this medical center model of engineering education. We believe that uniting engineering education, research, and practice will both elevate the profession of engineering and drive the technological innovation engine of the region and the nation in the 21st century, much the way that the evolution of the modern medical centers has done for the profession of medicine and the medical industry over the last half century.

As we developed our plan, we considered five key elements for a successful model of preparation for professional engineering practice, all taken from the medical center model. These key medical center elements, along with our proposed equivalent engineering counterparts, are listed in Table 1 and are described as follows.

- **Clinical Experiences at the Post-Baccalaureate Level**
  Following recommendations from the Flexner Report in 1910, medical schools across the U.S. have required a baccalaureate degree for admission.[11] Medical educators understand, as did Flexner, that clinical training will be most beneficial to individuals that have the educational maturity for the reflection, analysis, and synthesis necessary to process clinical experiences, and then to apply that learning in practice. For identical reasons, we believe engineering internships and cooperative educational experiences are most meaningful for students at the post-baccalaureate level, and that a practice-based post-baccalaureate education is the optimal pre-requisite for entry into the profession.

- **Incorporation of Clinical Experiences into Program Learning Outcomes**
  The accreditation standards set by the Liaison Committee for Medical Education (LCME) explicitly state that "the curriculum of a medical education program must include clinical experience in primary care."[12] Medical education learning outcomes include a balanced blend of basic and applied scientific principles with clinical practice skills that includes interactions with real patients. As mentioned previously, ABET learning outcomes and curricular content requirements can certainly be met, and most usually are, without any

Table 1. The Medical Center Model for Engineering Education

Key Medical Center Elements	Equivalent Engineering Elements
Clinical Experiences at the Post-Baccalaureate Level	
Professional doctoral level, practice-based education for future practicing physicians	Professional master level, practice-based education for future practicing engineers
Incorporation of Clinical Experiences into Program Learning Outcomes	
LCME accreditation requirement for clinical experience	Internship woven into required program learning outcomes
Appropriate Mix of Research and Clinical Faculty	
Appropriate mix of clinical faculty (practicing physicians) and research-oriented faculty	Appropriate mix of clinical faculty (practicing engineers) and research-oriented faculty
Industry Ownership of Professional Practice Training	
Teaching hospitals that understand and accept their role in training the next generation of physicians	Engineering-related corporations and government agencies – large and small – that understand and accept their role in training the next generation of engineers
Clinical Sites	
Tertiary care centers that operate a broad spectrum of clinical specialties which provide multiple opportunities for meaningful learning experiences in the practice of medicine	University-Industry cooperative that includes multiple opportunities for meaningful learning experiences in the practice of engineering, including: 1) realistic laboratory and design experiences, 2) internships redesigned as meaningful learning experiences, and 3) joint research and development activities

student "clinical" experiences that include interaction with real customers and practicing engineers. Absent any significant change in the expected program learning outcomes for engineers graduating from ABET-accredited programs, it is up to each institution to incorporate clinical experience requirements into their program requirements and their particular learning outcomes.

- **Appropriate Mix of Research and Clinical Faculty**
  Medical Center faculties include an appropriate mix of M.D. practitioners (clinical faculty) with Ph.D. researchers (research faculty). The researchers are involved in the teaching and mentoring of Ph.D. candidates in the medical sciences, but they also teach the M.D. candidates in the basic biomedical sciences courses. The practitioners are primarily involved in the clinical training of the M.D. candidates, and they also typically have a significant clinical practice assignment at the teaching hospital. Most engineering colleges are largely comprised of the research faculty type, who occasionally do outside consulting. Engineering clinical faculty would be persons with significant industry experience but who also have academic credentials and pedagogical capabilities. In

addition to teaching practice-based courses, engineering clinical faculty would coordinate industry activities, and facilitate experiential learning of professional practice.

- **Industry Ownership of Professional Practice Training**
  The medical services industry has a deep understanding of the need to hire medical professionals (physicians, nurses, etc.) that are adequately prepared to handle responsibility for human life from the first day of employment. That is why they are heavily invested in the clinical training of B.S.N. and M.D. candidates. In fact, teaching hospitals typically market that they are at the forefront of medical practice because they are teaching hospitals. Corporations and government entities that hire engineers need to also recognize that engineers are responsible for human life, and that serving as clinical teaching sites for engineers can be used to boost their prestige. More often than not this type of activity, when engaged in at all, is currently considered to be community outreach and recruitment.

- **Clinical Sites**
  All medical centers include a teaching hospital where medical students are able to interact with real patients under the supervision of clinical faculty. Typically these are regional tertiary care centers that have a broad spectrum of clinical specialties and that receive referrals from a large population within the service region of the hospital. This allows the medical student to gain exposure to a wide variety of patient situations. If a medical center does not include a tertiary care center, the medical school will typically have a variety of off campus sites where clinical training can occur.

  Due to the nature of the engineering profession, a single practice-based teaching center like a hospital will be very hard to replicate. In lieu of a single physical site for engineering practice experiences, we propose that the long-standing standards for hands-on experience (laboratory and design projects, internships, and research projects) can be made more meaningful by a close collaboration with an appropriate industry partner, or a consortium of partners. With appropriate industry involvement, these classical hands-on experiences can be the "professional spine" – the "engineering equivalent of the clinical dimension of medical preparation" and provide the "place to explore professional practice" as recommended by the 2007 Carnegie Foundation report on the future of engineering education.[1] In the following section we will illustrate an example with a specific industry partner at our institution.

A Prototype Case with an Industry Partner

We have initiated the first step toward development of a medical center-type model by establishing a prototype for the practice-based education of engineers through a partnership with Lockheed Martin Aeronautics Company (LMA). Through this partnership we have embarked on the following initiatives aligned with the key success factors listed in Table 1 and described above.

- **Clinical Experiences at the Post-Baccalaureate Level**
  Following the recommendation from Duderstadt[2] and the Engineer of 2020,[13] we are developing a new BS degree program that includes a broad-based curriculum of engineering design, project management, and innovation, along with business, communication, ethics, and social sciences.[14] For optimal preparation for professional engineering practice, it is recommended that this foundation be followed by post-graduate study, via a professional Master's degree program, in a specific discipline or concentration. Our first professional Master's degree program is in Systems Engineering.

- **Incorporation of Clinical Experiences into Program Learning Outcomes**
  The Systems Engineering program requires a 3 credit hour mandatory practicum in which students are hired full-time by partner corporations to work in teams on an actual company project, usually occurring during the summer period and lasting a minimum of 500 professional practice hours for the students. Students are expected to prepare briefings for technical leaders and executives in the sponsoring company in addition to the creation of written internal memoranda or technical reports. We consider the practice to be similar to a capstone project except that students are placed in realistic environments where they interact with practicing engineers and their customers, and are exposed to the dynamics of leading, advocating, communicating, and dealing with technical and non-technical issues in a multidisciplinary team.

- **Appropriate Mix of Research and Clinical Faculty**
  To facilitate the practice-based educational programs, we have instituted a novel non-tenure-earning track in the College of Engineering with the title Clinical Professor. Clinical Professors will generally be involved in teaching classes in the professional Master's degree programs, and coordination of industry projects. Clinical Professors will normally have significant industry experience in the field of study, but will also have experience in didactic activities as well. Our first Clinical Professor was hired to lead the Systems Engineering program.

- **Industry Ownership of Professional Practice Training**
  LMA is a recognized leader in the design, development and production of high precision aircraft. They also recognize the impact of engineers as the innovation agents for their enterprise, and the importance of hiring engineers that are ready to contribute to the corporation immediately upon hire. As such, they understand the important role that they need to play in the education of those engineers. Our contacts inform us that LMA has a goal that 80% of their new graduate hires have a previous positive internship experience with the corporation. They have partnered with us to provide an integrated program of practical experience through internships, and also on-campus laboratory and research environments as well.

- **Clinical Sites**
  Our prototypical partnership with LMA includes three fundamental elements of a fully-integrated practice-based curriculum: 1) realistic laboratory and design experiences, 2) internships as meaningful learning experiences, and 3) joint research and development

activities that range from fundamental discoveries to the development of innovative products and business development. We will briefly describe those initiatives here.

Mechanical Engineering Learning Laboratory. Laboratory and design-build experiences have long been standard hands-on experiences for engineering students. Our desire was to ensure that these experiences are appropriate training for industrial practice. The Mechanical Engineering Learning Laboratory is now supported by LMA as they have seen the laboratory's potential to meet industry demands for a prepared workforce while promoting student interest and success in mechanical engineering. The focus areas for the laboratory were selected because they address industry concerns, like those of LMA's, and include: mechanical measurements, materials and manufacturing, electro-mechanical systems, energy systems, and flight systems. The laboratory has been fully designed in collaboration with the corporation. The laboratory provides practice experiences to the mechanical engineering students and allows them access to the tools and processes used in industry. The laboratory experience consists of three longitudinally integrated learning segments: (i) basic measurements, (ii) performance evaluations of complex mechanical systems, and (iii) system integration.

The basic measurements segment has been organized to introduce the students to the measurement of physical properties in mechanical, thermal, and flow systems. In this segment, students perform experiments related to force and motion, pressure, temperature, fluid properties, flow rate, and velocity. Students learn to use analog, digital and DAQ based instrumentation and various signal processing techniques. Students are required to statistically analyze data and report their findings in written laboratory reports. This improves both their statistical background for data integrity and their communication skills. The second segment builds off the engineering measurement techniques acquired in the prior segment and expands on those to understand various theoretical concepts and performance parameters of complex mechanical systems (especially those involving interactions of thermodynamics, fluid flow, heat transfer, and structural mechanics). Experiments for this learning segment are designed for undergraduate instruction and are instrumented with state of the art data acquisition systems.

The system integration segment has been organized as a capstone design course where students conceptualize, design, integrate, and test complex mechanical systems. They then report the results in oral and written form. To complete this segment successfully, participants have to design mechanical engineering systems from validated theoretical concepts, characterize and evaluate performance, and control and monitor mechanical engineering devices. One of the recent projects involves developing a torsional thrust stand to measure steady-state and pulsing performance of 5N class rocket engines. In this joint project between NASA-Jacobs Technology, and the UTEP NASA University Research Center, students are applying their fundamental skills to design, build, and test practical hardware. While doing so, they are also learning engineering best practices in project management, safety, and quality assurance in conjunction with the industry partner.

Systems Engineering Internships. Internships are also commonly used as a means for obtaining practical experience. To approach the medical school model of an internship, our desire was to structure the internships as meaningful learning experiences. For the past three summers LMA has hired students from our Systems Engineering MS program to work on projects at their site. These students worked on projects integral to the LMA operations and interacted with engineers at all levels, and the UTEP clinical professor acted as a preceptor to guide the student's reflection and learning throughout. All of these students were then hired by LMA upon graduation, and those new hires were involved in the supervision of new students the following year.

We have a process in place with LMA where our faculty discusses the needs and priorities of the corporation to define areas of possible collaboration. Once these areas are understood and prioritized, LMA and UTEP develop a Statement of Work (SOW) of expected outcomes and deliverables for on-campus developmental projects and/or on-site deployment of students under a particular project. For on-site deployment students interested are encouraged to submit their application for LMA review. After LMA review they choose candidates to be interviewed and LMA decision makers select the students they want to hire for on-site deployment which usually happens during the summer. During the interview process, LMA managers and technical personnel describe the projects, introduce the project manager, and detail the responsibilities of the students while on the LMA premises. These projects are usually mid- to long term projects that allow different phases of development and future follow up by the project manager within LMA and by the clinical faculty member within the university. For instance, during three consecutive summers our students have been working on modeling and simulation of gun accuracy by assessing current tools, adding non-linear effects to existing models, employing control systems analysis to simulate conditions to achieve accuracy within near field of view, and analyzing the integrated system (radars, frames of reference, gun, matching to steering algorithms, etc). Another important example has to do with Integration, Verification and Validation (IV&V) of a technology refreshment research program that has been continuously developed on-campus with supervision of the project manager and technical leaders in LMA. Both the modeling and the IV&V projects are still planned for continuation during 2011.

Assessment of outcomes and objectives during student internships incorporate ABET guidelines and have been agreed upon with LMA. Mastery of outcomes is assessed through evaluations of team members (peer level), LMA managers' evaluation of technical presentations, on-campus and on-site reports, and official feedback and grading of the team and of each individual student by the clinical professor. A major component of the on-site practice is the opportunity given to the students to present their work to technical managers and LMA technical teams and to have exposure to executives, in charge of different programs, who hear and evaluate their work. A final professional technical report is written once the students get back to school under the supervision of a clinical professor. These reports are then sent for review and final approval by LMA.

The implementation of this model has presented major challenges in the financial and academic arenas. On the one hand, the differing financial models between academia and industry were overcome through the development of contractual mechanisms (with a strong customer-supplier relationship) committing to have qualified resources, to deliver valuable work products on time and cost, and to manage the projects through the LMA project manager and the university clinical professor. On the other hand, it is critical to get the university and the faculty members to embrace and understand the corporate environment and the corporation practices. This challenge has to do with the different cultures and pressures, e.g., industry is more interested in stakeholder value-added, on increased competitiveness and processes improvement, etc. while the academic culture is more geared toward insightful papers, basic fundamental research and individual reward systems. Our experience demonstrates that the model works better when the involved faculty members have also been industry practitioners (clinical professors).

Collaborative Research and Development Activities. While most Colleges of Engineering perform a significant amount of contract work for industry, our desire was to create a long-term collaborative relationship with a corporation for ongoing research and development activities. Over the past 10 years, we have developed a unique combination of capabilities in additive manufacturing and direct print technologies. Together, these technologies can manufacture functional objects the fabrication of which requires no re-tooling and results in little material waste. Recently, we have entered into a partnership with LMA to perform collaborative research and development centered on those capabilities to provide needed technology and services to LMA's Advanced Development Program (ADP). This partnership is subsidized by the Texas Emerging Technology Fund (ETF). The purpose of the ETF program is to provide the infrastructure to support collaborative arrangements between Texas corporations and universities to drive research and commercialization around a certain emerging technology. The goal of the academic-industry partnerships is to create value for the corporation, promote innovation and new business development, and, most importantly, provide practical training to students with industry-relevant research and development activities.

These partnerships leverage the strengths of the university in terms of research and development in the technology areas mentioned above. The process begins with faculty, students and university researchers visiting LMA to present the wide range of capabilities of the university. Potential collaborations are identified where LMA needs and UTEP capabilities coincide. The SOW methodology described above for the Systems Engineering efforts provides a framework for implementing LMA-directed R&D projects undertaken within the university research laboratories. Typically lasting 12 months, these projects include support for students, faculty and university researchers and are aligned with the academic calendar to be better suited for the university environment – in which research students require support throughout the entire semester. Kick-off and status meetings are held at the beginning and at regular intervals throughout the projects respectively and generally include LMA engineers and scientists visiting the university – which is preferred as the LMA employees can dedicate focused time to the projects while at the university without being distracted by general day-to-day business.

Successful example projects include exploring and optimizing manufacturing technologies to provide new capabilities for the company to *print* desired electrical and other active elements on various conformal surfaces. Optimization of printing processes for a variety of materials includes increasing speed of operation and improving the mechanical and electrical aspects of the printed surfaces through the use of state-of-the-art lab equipment within the university. Other projects include the use of a relatively new metals-based additive manufacturing technology, which has limited deployment in industry or academia but holds promise to revolutionize the manner in which metal components are fabricated. The university not only has the equipment in-house but also is a leader in understanding the metallurgical properties of fabricated structures. LMA is interested in the technology in order to build unique and customized metal devices, which include various conventional aircraft components as well as future designs that incorporate honeycomb and foam-based internal structures to maintain strength while reducing weight – an unavoidable trade-off in the aerospace industry. All of these projects collectively have 1) strengthened the research infrastructure of the university, 2) trained a large group of engineering students, and 3) helped identify new applications of a manufacturing technology for which the university maintains a leading research role.

Conclusions and Recommendations

There have been a plethora of studies and reports commenting on the dire straits of the nation's innovation advantage[e.g.15] and the need to transform engineering education.[e.g.13] We concur with Duderstadt's[2] recommendation that a potential solution to both issues resides in the movement of engineering education towards the academic medical center model, where engineering education, research, and practice are well-integrated. This model, then, leads to active university-industry-government partnerships in education, research, and the practice of engineering as the leading edge innovation drivers of the country, replacing the former corporate research and development laboratories of the mid-20th century mold. It also includes putting professional practice experiences at the forefront of the curriculum, rather than at its margins.

We have initiated just such a partnership with a corporation that employs large numbers of engineers and is well known for its innovation impact on the nation – in 2008 the LMA ADP was honored by President Bush with the National Medal of Technology and Innovation. Through this three year partnership (thus far), and in comparison with the arguably highly successful medical center model, we have determined the following critical success factors:

- Clinical Experiences at the Post-Baccalaureate Level
- Incorporation of Clinical Experiences into Program Learning Outcomes
- Appropriate Mix of Research and Clinical Faculty
- Industry Ownership of Professional Practice Training
- Clinical Sites – industry practice based laboratories, internships, and collaborative research

We have presented here an isolated case of a partnership with a single corporation, and the integration of professional practice into a single graduate level program – the MS in Systems Engineering. With this successful prototype case in hand, we are currently replicating this model with multiple companies, large and small, and across a variety of professionally-oriented

Master's degree programs in the College. Within the decade we plan to have this model implemented in all thirteen of the College's Master's degree programs.

The culminating theme arising from the recent Carnegie Foundation study *Educating Engineers*,[1] is best summarized with the following quote:

> "If engineering students are to be prepared to meet the challenges of today and tomorrow, the center of their education should be professional practice, integrating technical knowledge and skills of practice through a consistent focus on developing the identity and commitment of the professional engineer. Teaching for professional practice should be the touchstone for future choices about both curriculum content and pedagogical strategies in undergraduate engineering education."

To arrive at our proposed model that we describe and recommend in this paper, we have combined this recommendation with the following from Duderstadt's *Engineering for a Changing World*:[2]

> "Working closely with industry and professional societies, higher education should establish graduate professional schools of engineering that would offer practice-based degrees at the post-baccalaureate level as the entry degree into the engineering profession."

The implementation of this medical center model in a university engineering setting will allow for effective collaborations with industry locally and nationally as well as with government agencies that hire engineers. But most importantly, the medical center model for engineering education and research will provide an optimal means to educate and train engineering students for preparation as effective professional engineers. As designed, this well-integrated cooperative approach for university-industry partnerships also promotes innovation, commercialization, and economic development.

References

[1] S.D. Sheppard, K. Mucatangay, A. Colby, W.M. Sullivan, Educating Engineers: Designing for the Future of the Field, Indianapolis: Jossey-Bass, 2008.

[2] J.J. Duderstadt, "Engineering for a Changing World," Millennium Project, University of Michigan, Ann Arbor, Michigan, http://milproj.dc.umich.edu/, 2008, last access 1/18/11.

[3] Smollins, John-Pierre (1999), "The Making of the History: Ninety Years of Northeastern Co-op", *Northeastern University Magazine* **24** (5), May 1999, http://www.northeastern.edu/magazine/9905/history.html, last retrieved 1/1811.

[4] "Criteria for Accrediting Engineering Programs" (2011), ABET Engineering Accreditation Commission, Baltimore, MD: http://www.abet.org/Linked%20Documents-UPDATE/Program%20Docs/abet-eac-criteria-2011-2012.pdf, last accessed 1/18/11.

[5] Crow, C. (1997), "Cooperative Education in the New Millennium", *Cooperative Education Experience*, Columbia, MD: Cooperative Education Association, pp. 1–5 (ED 414 433).

[6] John, J. E. A.; Doherty, D. J.; Nichols, R. M. (1998), "Challenges and Opportunities for Cooperative Education", *Journal of Cooperative Education* **33** (2): 10–16, Winter 1998.

[7] Kao, John. Innovation Nation, New York: Free Press, 2007.

[8] Coalition of Urban Serving Universities (2010) "Urban Universities: Anchors Generating Prosperity for America's Cities, http://www.usucoalition.org/downloads/part6/USU_White_Paper_Report_2010.pdf, last accessed 1/18/11.

[9] Bowen, W.G., Chingos, M.M., and McPherson, M.S. Crossing the Finish Line, New Jersey: Princeton University Press, 2009.

[10] Berdahl, R. M. "The Future of Flagship Universities," Texas A&M Convocation Address, October 5, 1998. http://cio.chance.berkeley.edu/chancellor/sp/flagship.htm, last accessed 1/18/11.

[11] Cooke, M., David, M.I., Sullivan, W., and Ludmerer, K.M. (2006) "American Medical Education 100 Years after the Flexner Report," N Engl J Med. 355:1339-1344.

[12] Liaison Committee on Medical Education (LCME) (2010) "Functions and Structure of a Medical School: Standards for Accreditation of Medical Education Programs Leading to the M.D. Degree," http://www.lcme.org/functions2010jun.pdf, last accessed 1/18/11.

[13] C.W. Clough, et al., The Engineer of 2020: Visions of Engineering in the New Century, Washington D.C.: National Academies Press, 2004.

[14] Schoephoerster, R.T, and Golding, P. (2010) "A New Program in Leadership Engineering," Proceedings of the 2010 IEEE Transforming Engineering Education: Creating Interdisciplinary Skills for Complex Global Environments, April 6-9, Dublin, Ireland.

[15] Augustine, N.R. et al., Rising Above the Gathering Storm, Revisited, Washington D.C: National Academies Press, 2010.