A Graduate Curriculum for Engineering Leadership

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***Abstract* - The increasing global competition in technology industries puts a premium on those exceptional engineering leaders who can direct multidisciplinary teams to bring innovative technical ideas to the market in a short period of time meeting all cost goals. An educational program that would accelerate the development of such engineering leaders would be of great educational and societal value. We describe a new educational initiative, the Gordon Engineering Leadership Program, enabled by a gift from the Gordon Foundation. The curriculum of the program features a thesis-scale "Challenge Project" based on the academic advisor/dissertation model, but directed toward commercialization or deployment of a new technology. The Challenge Project will be supported by new courses in "Engineering Leadership" and "Scientific Foundations of Engineering" to give the graduate a broad scientific framework to support rapid "back-of-the-envelope" quantitative assessment of technology problems, an understanding of the non-technical issues of commercialization, and a successful experience of leading the development of a product in a time-critical environment.**

Index Terms - engineering, leadership, graduate education, curriculum

INTRODUCTION

The National Academy of Science publication *Rising Above the Gathering Storm*[1] has focused attention on science and technology leadership in the context of national competitiveness. The recommendations of the study are primarily quantitative. They include increasing the K-12 pipeline and the number of university bachelor's degrees awarded in science and engineering, and increasing support for fundamental research that leads to technological innovation. These recommendations suggest that US science and engineering educational institutions continue to do what they are doing now, but increase the scale.

An alternate viewpoint would be to invest in strategies for education that increase the value added of education in producing "engineering leaders." We define engineering leaders as those engineers who are capable of leading a multi-disciplinary team to drive a project from concept to final product under the pressures of deadlines, limited budgets, and technical hurdles. The number of these engineering leaders is the workforce is low (one estimate is 1 in 1000 practicing engineers[2]), but they contribute disproportionately to the advance of technology. Success in the marketplace attracts capital investment and unleashes the power of large-scale production – incorporating incremental technical and manufacturing improvements and economies of scale – to reduce prices, increase markets, and fuel technological spin-offs.

The staggering technological advances of the information revolution – computer and communication products such as cell phones, personal information managers, and portable music systems – were frequently seeded by relatively small groups of highly technically-skilled engineers in a division of a large company or in a start-up company. The engineers that led these groups required a combination of keen technical expertise, intuition, business acumen, team leadership skills, vision, and a sense of urgency – there is only a relatively short window of opportunity for product development before resources are redirected into other opportunities.

The skills that make a successful engineering leader as described here are largely innate, but there is learning curve, probably 10 years of work as a practicing engineer, before someone with the qualities of an engineering leader matures in a supportive environment into a technology champion capable of driving the kind of technology breakthrough we have been discussing. Whether there is an educational path that would significantly shorten that timeline is an open question.

At Northeastern University, we have been the beneficiaries of a generous gift by Bernard Gordon, an engineering pioneer in the field of analog-to-digital conversion and medical technologies, to establish an Engineering Leadership Program as a key educational

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component of the Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS), a four-university NSF Engineering Research Center. The Gordon Engineering Leadership Program has been charged with the challenge of defining and implementing a curriculum to accelerate the development of engineering leaders.

THE GORDON ENGINEERING LEADERSHIP PROGRAM

The Challenge Project

The model for advanced graduate education in universities since medieval times has involved a prolonged apprenticeship period related to the completion of a doctoral or master's thesis dissertation. The expression of this model in the PhD programs of American research universities, supported by generous government funding, has become the standard for graduate education of academic and research professionals. Students from all over the world come to US universities to do PhD research through the thesis-advisor/dissertation method, which has its roots in the apprenticeship process.

Government-supported university research has proven to be a fruitful environment for both scientific discovery and academic training in research. In the process of completing a PhD dissertation, capable students discover that they have surpassed their advisor in knowledge of their thesis area. The intellectual self-confidence engendered by this period of intense study and mastery allows PhD graduates to take their own place as accomplished academics or professionals.

A PhD is not an ideal path for an aspiring engineering leader, both because of the length of the process and because PhD theses are focused on research problems with application horizons of ten years or more. In contrast, engineering leaders in industry are focused on the equally challenging problems of rapid technology transition from development to product prototype to market. Academics typically consider commercialization problems to be uninteresting and not appropriate thesis topics. A different measure of the relative difficulty of research and development breakthroughs and of bringing a technology to the market can be judged by the relatively small number of the patents granted to academic researchers that are actually licensed for production.

The Gordon Engineering Leadership Program is built around the "Challenge Project," an intensively mentored, thesis-scale, 8-semester-hour experience of product or process development resulting in system integration and/or commercialization of the technology within a year's residency in the program. This intense individual project carried out by the student/engineering leader under time pressure and real economic constraints is the analog of the thesis experience for someone whose goal is a career in technology deliverables and deployment rather than in research. We believe that the self-confidence and skills gained in such a project will be a life-changing career experience for the industrial engineer, comparable in transformative power to the well-established role of the PhD dissertation for an academic researcher.

The creation of appropriate Challenge Projects will be a key to the success of the program. A typical program participant will be a young engineer with two to five years of employment experience identified by his employer company as having leadership potential. The company will identify a Challenge Project mentor from inside the company and a faculty mentor will be identified by the Gordon program. The candidate, employer mentor, and faculty mentor will jointly define a Challenge Project that is important to the strategic interests of the employer and capable of resolution within the year time-frame of the program residency. A detailed project plan will be drawn up before the participant enters the program, identifying the goal and action plan for the project, resources available from the employer and within the Gordon center to accomplish the objectives, and milestones or go/no-go decision points.

The project plan will be modified as the program progresses based on the development of the project and lessons learned from the course work described below. Nevertheless the requirement for a preliminary but detailed project plan on entrance to the program will greatly increase the chances of a successful outcome by motivating careful consideration of the necessary elements of the program even before the beginning of the residency. The project plan will also serve as a vehicle for feedback from the project mentors who can identify weaknesses or issues of concern where the project may need to plan for more resources.

Key elements of project success will include employer commitment and buy-in, the support and active engagement of appropriate employer and university mentors, a detailed predefined project plan, and the resources available from the employer and the multi-university research environment of the Gordon-CenSSIS Engineering Research Center. A few projects will be sponsored by the Gordon Center to demonstrate the commercial potential of promising technologies that arise from university research and development.

Candidates for program participants with Center-supported projects will be identified from among recent BS or MS graduates with exceptional academic and leadership potential and significant employment experience through internships or the extensive Northeastern University cooperative education program. While the Center-supported participants will not be full-time employees at the time of admission (otherwise they would be working on company-identified projects), the more capable graduates of an intensive cooperative education program such as that at Northeastern University frequently have industrial experience in positions of responsibility in widely differing company environments and are extremely knowledgeable about technology application techniques.

Credit for the Challenge Project will be granted only after a presentation and defense of the work before a committee consisting of the two advisor/mentors and at least one additional faculty member. While not every Challenge Project will result in the successful commercialization or deployment of a product, the committee must be convinced that the candidate has either demonstrated the success of the project concept or proven beyond doubt that the concept is irreparably flawed. The ability to define, evaluate, and defend a definitive no-go decision about a potential technical product in a short period of time is also a valuable skill for an engineering leader, as it allows the effort to be redirected to more promising projects without excessive wasted effort.

Required Course Work

In addition to the 8-semester-hour Challenge Project, each program participant will be required to enroll in two newly created 4-semester-hour course sequences in “Engineering Leadership” and “Scientific Foundations of Engineering.” These two courses have been selected to address existing gaps in engineering education.

The tendency of engineering education to focus too narrowly on a particular specialization has long been noted[3]. This is a natural consequence of the explosion of new technology and the reluctance of engineering programs to remove older material from the curriculum. The result has been that engineering programs are typically so packed with field-specific technical material that there is little time for multidisciplinary studies, system-level overviews, or even to emphasize the connections between the subfields within a specific engineering discipline. Thus BS and MS engineering graduates have rarely been trained to understand a systems approach to problems and have little background to evaluate problems outside of their narrow discipline.

The deleterious effect of this specialization on the ability of engineers to redirect their careers out of obsolescent areas has been noted[3]. The inability to “see the forest for the trees” is also an inhibiting factor in developing engineering leaders. One of the characteristics of a technology driver is an ability to address areas outside of his or her area of technical competence. Engineering education characterized by a focus on technical details rarely gives the graduates an adequate framework for attacking problems in an unfamiliar field.

The ABET accreditation criteria revisions in the year 2000 were formulated in part to address the narrow academic focus of traditional engineering programs. They require programs to demonstrate that their graduates achieve proficiency in such broad outcomes as “an ability to function on multi-disciplinary teams” and “recognition of the need for, and an ability to engage in life-long learning.” The ABET criteria have had a profound influence on undergraduate programs, leading most engineering departments to include some type of “capstone” experience in their curriculum. While capstone design experiences have broadened engineering education somewhat, they are most often tacked on to the undergraduate program with little curricular connections or support. Students solve their capstone problems with ad hoc techniques similar to those they adapt when they enter an industrial environment. Capstone projects serve as a transition to industry, possibly reducing the period of adjustment to a work environment, but do not necessarily give students a systematic basis for solving system problems.

The Gordon Program course work is intended to give students an intellectual framework for addressing systems-level problems. The Engineering Leadership course includes topics in four areas: product engineering, market assessment, engineering excellence, and engineering leadership. Product engineering includes topics in system design and engineering, multi-disciplinary integration, product development process, and project management, including scheduling, cost control, and program risk. Market assessment includes topics in engineering economics, translational research, business plans, intellectual property, and product risk assessment and mitigation. Engineering excellence covers topics in manufacturability, reliability, serviceability, quality control, and volume production. Engineering leadership covers issues of team-building and management, conflict resolution, leadership styles, ethics, organizational behavior, and morale.

The Engineering Leadership course touches on many topics that would be covered in a business administration program, but it is tailored for engineers engaged in the leadership of a technical project. This material is rarely included in an engineering curriculum unless students take courses in engineering economics or business. By focusing the material toward engineers engaged in leadership of a technical project, the relevant system engineering and organizational concepts will be featured and emphasized.

Instructors of this course will be engineers with an extensive background in industry. As examples, one of the authors of this paper has served as the vice president for engineering of a major defense contractor and another has served as an industrial program manager for a number of technology industries. We will also use personnel from the Industrial Advisory Board of Gordon-CenSSIS as guest lecturers.

The other required course, Scientific Foundations of Engineering, addresses a second deficiency in undergraduate engineering education. Most engineering students take their required physics, chemistry, or biology science courses in their freshman or sophomore year. The courses are typically not popular with engineering students and the material is largely forgotten by the time the students graduate.

An engineering leader, however, needs to have a framework of fundamental scientific knowledge to communicate on the basis of first principles with members of a multidisciplinary team and to make fast “back-of-the-envelope” calculations to assess solutions and check assumptions. Further, in a world in which information is instantly accessible over the Internet, the need to have a framework with which to organize and evaluate that information is paramount. A clear understanding of fundamental cross-cutting scientific principles can be invaluable in identifying useful information and discarding unreliable or inapplicable assertions.

The Scientific Foundations of Engineering course will revisit, at a higher and more unified level, the physics underlying electrical and mechanical engineering practice, including mechanical and electrical properties of materials, thermal and fluid properties of matter, wave phenomena, and quantum physics. The mixing of examples from mechanical engineering (elasticity, vibration, and acoustics) and examples from electrical engineering (optics and spectroscopy) as illustrations of the same fundamental physical laws will be a characteristic of the course. Chemical and biological concepts will be introduced as time permits and linked to the microscopic atomic physics of matter. Conceptual understanding will be emphasized, but with enough rigor that the mathematical similarities in different phenomena can be appreciated and applied to other related problems.

A revisiting of fundamental scientific concepts at a graduate level, making use of discipline-specific engineering examples and drawing connections across fields, is an application of the concept of a spiral curriculum – studying the same material at successively higher levels of sophistication. The deeper insight engendered by such an approach will provide intellectual self-confidence for the engineering leader when he interacts with experts outside of his disciplinary background.

Elective Course Work and Degree Programs

The engineering leadership program that we have laid out is based on mastery of the science and engineering underlying technical innovation. We are convinced that an engineering leader cannot identify and surmount technical obstacles or command the respect of a multidisciplinary team without fully understanding the technology. Thus there is a need for depth as well as breadth in the educational preparation of the engineering leader. There is provision in the program for the participants to take four technical electives from the graduate engineering courses offered in their field. Course will be selected by the student in conjunction with his academic and industry mentor on the basis of relevance to the Challenge Project and long-range career and educational goals.

Participants who successfully complete the 16 semester hours of the two required courses and their Challenge Project will be recognized with a graduate certificate in Engineering Leadership and by their designation as Gordon Fellows. Those who complete an additional 16 semester hours of graduate technical electives will receive, in addition, an MS in their engineering discipline. A new master's degree, MS in Electrical and Computer Engineering Leadership, has been created to differentiate this program in technology deployment or commercialization from the traditional research-oriented electrical engineering master's degree program.

CONCLUSION

Technological innovation is most often driven by teams of engineers led by a technically adept and far-sighted leader. The key role of these engineering leaders in both start-up and established companies in creating economic value and national competitiveness has not received much attention. Current discussions of national technological goals have focused almost exclusively on increasing the number of science and engineering graduates with little discussion of improvements in the training to foster the creation of engineering leadership qualities.

The Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems has established a graduate program in engineering leadership designed to accelerate the development of engineers who can lead multidisciplinary teams to drive research and development breakthroughs to deployment or commercialization. Becoming a leader of technological change requires technical mastery as well as business savvy. The Gordon Program adapts the proven academic thesis-advisor/dissertation model to the problems of commercialization by introducing a thesis-scale Challenge Project mentored by academic faculty and senior engineer/managers from the students' industry or government agency employers.

The program curriculum emphasizes technical depth and breadth as well as non-technical skills of systems oversight and team-building. A course in scientific foundations of engineering revisits scientific fundamentals to yield a deeper understanding of inherent limitations in multidisciplinary projects and to enhance the ability to rapidly assess proposed technical solutions. Technical depth and intellectual self-confidence are instilled by elective graduate courses in a technical disciplinary area. A course in engineering leadership provides an introduction to systems engineering concepts, economic considerations, and organizational skills.

The goal of the program is to create an academic path for the development of new technology leaders, possessing strong technical skills and the ability to oversee multidisciplinary projects from inception to completion in deployable or marketable systems. The program fills the gap between traditional engineering and business educational paths and represents a new approach to technical training for technology pioneers.

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