Enhancing Engineering Education through Engineering Management

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Abstract

Engineering Management courses are added to a traditional engineering curriculum to enhance the value of an undergraduate's engineering degree. A four-year engineering degree often leaves graduates lacking in business and management acumen. Engineering management education covers topics enhancing the value of new graduates by teaching management skills that are immediately applicable. Thermodynamics or circuits or heat transfer may not be immediately useful to an engineering graduate. Companies often use software (or software versions) unfamiliar to a graduate or their specialization requires a lengthy break-in period. Team building using personality inventories or behavioral profiling or conflict resolution techniques are immediately applicable in any work setting. Project management and engineering economics are applicable if tailored to a particular engineering genre or workplace environment. A coordinated set of courses designed to give a student a lead over other workplace entrants has been shown to enhance the likelihood of a person being hired based on feedback from employers, alumni, and advisory boards.

Keywords: Economics, team, interviewing, management, performance, reviews, personality, inventories, business, practical

Introduction

The roots of engineering management education at Vanderbilt date back to the mid-1960s,when Robert Garner, a Board of Trustees member and former president of the World Bank, believed that a need existed for people to be educated in both technology and management in order to better manage the increasingly large and complex industrial and government projects. Thus the first engineering management professor was hired and charged with designing a curriculum that contained quantitative methods, applied economics, and organizational theory. A psychiatrist was hired to teach applied behavioral science, then defined as the study of the human problems associated with the task of managing, or simply to "teach students how people feel about themselves and their jobs" (Jacobs, 1975). The graduate program was offered two years later and was "designed for the mature, experienced engineer—the average age [was] 32—and it [led] to the Master of Science degree" (Jacobs, 1975). The graduate program also contained a one-year internship where students applied their classroom work in a real-world industrial setting and then returned to campus to analyze their findings and prepare their theses. By 1970 engineering management was its own department offering undergraduate and graduate courses—arguably some of the most popular in the School of Engineering at the time.

For nearly 40 years Vanderbilt University has maintained the importance of enhancing traditional undergraduate engineering education by offering unique courses of study in engineering management. In a 1994 *Frontiers in Education* conference proceedings, the founding director of the formal management of technology minor program (in place since 1991) argued that, "the successful development and implementation of advanced technologies will require scientific and engineering excellence, and also effective technology management. (p. 375)" He also argued that issues involving "strategic planning, financial feasibility, the availability and cost of raw materials, innovative product development, human resources, project management, and the global competitive environment" (p. 375). must be considered when determining what the management of technology entails and how an academic program should be constructed.

During this time it was determined that about 50% of Vanderbilt's engineering undergraduates reached management positions within five years of graduation. This realization solidified the hypothesis that, especially at Vanderbilt, management education was important to preparing engineering students for their future careers.

The management of technology minor, as it was called then, was designed to provide students with a fundamental working knowledge of business processes, decision making, and problem solving strategies as they relate to high-tech enterprises. A secondary purpose was to make students more employable in their post-graduate endeavors by branding them apart from traditional engineering graduates, with whom they compete for increasingly scarce jobs.

The curriculum began as a grouping of courses involving technology and public policy, engineering economics, behavioral science, principles of innovation, marketing, forecasting, and project management. Student participation in the minor program increased for the first several years by nearly 50%. The added incentive that could have had much to do with the increase in participation was that the minor program— 15 semester hours— could be substituted in a variety of elective options. Faculty realized early-on that it would benefit students to find a way to embed the minor requirements into traditional curricula. The addition of courses simply for the sake of the minor was not considered a valid option given the costs to the students and the extra time required (Cox, Cekic, & Adams, 2010). This feature allows students not to have to take any additional courses beyond their traditional academic program. Evidence in the 60s through the early 80s was simply anecdotal, showing that the engineering management courses provide significant enhancement of students' success in their tra-

ditional engineering curricula, specifically in areas of project leadership, project management, group interaction, strategy development, and innovation.

Other attempts to quantify the effectiveness of the engineering management minor developed through advisory committee surveys and pre/post-graduation surveys, but the sample sizes were still small. It has only been recently, with the advent of social networks and the extensive use of "permanent email" addresses, that quantifiable feedback is beginning to emerge. LinkedIn, Facebook, and Gmail have become a standard within themselves for this purpose. It has not been decided how social media will affect the ability to gather post-graduation data on perceived benefits of engineering management education over the long-term. Companies want graduates to "hit the ground running" in management and seem reluctant to spend the money to hire "seasoned" leaders when they can mold their own young staff (Rappaport, Bancroft, & Okum, 2003).

Over time the minor requirements have changed. Initially the minor consisted of two required courses and three elective options based on student interest. In 1999, the minor program was rewritten; new courses were added, less-rigorous and outdated courses were deleted, and the requirements changed to four required courses and one elective option. The reasoning behind this change was simple: the students enrolled in the minor had a more uniform experience, thus leaving the program with a similar set of knowledge, skills and abilities. This simplified curricular structure also placed less burden on academic advisers, who numbered very few in the early years in a department with no dedicated faculty.

Current Program

Currently, undergraduate enrollment in the renamed engineering management minor program is at an all-time high. Nearly 50% of the graduating seniors in the spring of 2010 completed the requirements of the minor program ($n \approx 120$). Nearly one-third of all undergraduates (sans first-year students; $n \approx 350$) have formally declared their intent to complete the minor program, with an unknown number pursuing the minor without having declared it already. The curriculum has undergone several changes in the past decade. During this time program faculty would receive feedback from former students stating how they could have benefitted more from additional course offerings and exposure to additional concepts. Also, traditional engineering departments' (i.e. EE, ME, ChemE, CE, etc.) advisory boards would recommend specific topics within engineering management be taught to students. Those notes were shared with engineering management faculty by the respective department faculty. While feedback was anecdotal and informal, the merits of both the alumni and industrial members' requests were seriously considered. Thus, a course in finance and accounting for engineers was added, as well as an entrepreneurship course and a supply chain management course. The introductory course has been retooled slightly to focus more on technology strategy within technology-based companies of various sizes and industries. The course in program and project management included disaster response and project security components in its syllabus, as requested by companies and government agencies hiring our graduates. The addition of elective courses to the program has resulted in smaller class sizes in those courses and, unfortunately, some competition between courses due to constraints on class scheduling. Such competition is a perennial problem and little can be done until more instructional space is acquired. More recently students have requested to take some upper-level courses earlier in their academic program in order to use those skills learned to obtain summer internships. This changing landscape has increased the challenge in undergraduate advising as the program copes with growing enrollment and has led to considerations on changing the program structure to increase flexibility and choice in course selection.

The fifteen semester-hour undergraduate minor is completed with four required courses and one Engineering Management elective course of the student's choosing.

- Technology Strategy— A study of the problems encountered by executives and senior managers in the planning, organizing, and allocating of resources and in prioritizing, directing, and controlling technical activities. Students take on the role of CTO and develop a technology strategy for a pre-commercial technology in its infancy.
- Applied Behavioral Science—The "people part of management." Focus is on employees, customers, owners, and managers, with emphasis on skills and experience needed by managers in technical enterprises. The course covers personality inventories, handling conflict/marginal employees, per-

formance evaluations, interviewing, team building, deception detection, managing reprimands/rewards, handling sexual harassment, goal setting, and corporate culture.

- Systems Engineering—This course covers blending engineering disciplines in large-scale enterprises to reduce program costs by examining/modeling system integration to avoid failures and lessen duplicative costs. Partnerships with high-tech, local businesses on systems engineering projects is the focus of the last half of this course.
- Program and Project Management—This course covers methods for planning small and moderately-sized projects, as well as rapid prototyping. The course covers organizational structures and information management for project teams, as well as communications between project teams, clients, and government agencies. Cost estimation, scheduling, load/resource balancing, and quality management is covered, as are conflict resolution and project termination.

Elective Courses:

- Engineering Economy—The course covers the economic evaluation and comparison of alternatives: interest, periodic payments depreciation, criteria, and analytical procedures in investment decision-making, plant feasibility, ethical issues, and cost estimating. Course now includes credit default swaps, consolidated debt obligations, derivatives, bonds and inventory/personnel management—all added specifically in response to current financial conditions and operating environments for most companies.
- Finance and Accounting for Engineers—Finance and accounting topics are studied from the perspective of engineering professionals working in business organizations. Areas covered include the time value of money, capital budgeting, capital formation, financial accounting and reporting, performance measurements, and working capital management.
- Technology Marketing—This course covers marketing industrial, technology-based products and services from the inception of a product to end-use. Business marketing strategy, segmentation, distribution, and personal selling are explored through lectures, readings, cases, and individual student projects.
- Technology-Based Entrepreneurship—This course covers approaches to the identification and evaluation of opportunities, risks faced by entrepreneurs, market assessment, capital requirements, acquisition of venture capital, legal structures, and tax implications for starting a technology-based business.
- Production and Supply Chain Management—This course reviews manufacturing strategy, process analysis, product and process design, total quality management, capacity planning, inventory control, supply chain design, and advanced operations topics using modeling and case study analysis/spreadsheets.
- Technology Assessment and Forecasting—This course covers methods of assessing technological changes in the social, political, ecological, economic, legal, and institutional environments. Technology forecasting is treated in detail: intuitive thinking, exploratory techniques of trend extrapolation, normative techniques of relevance and perspective trees, scenario writing, etc. Government and industrial reports are used as case studies.

In the spring 2010 semester the engineering management faculty experimentally added a senior capstone course designed for interdisciplinary engineering majors who were also engineering management minors. The goal was to give an initially small group of seniors (n = 12) a capstone experience involving real companies and working with real clients as other disciplines' capstone courses do. Initial results suggest this experience was a success, and a second offering with more students and projects occurred in the spring 2011 semester. Evaluations from students, clients and external project evaluators (a team consisting of a serial entrepreneur, a venture capitalist, a corporate development fund manager, and an economic development executive) suggest the real-world, high-stakes context of the project course significantly added to students' self-efficacy and ability to complete a complex project.

Informed Relevancy of Course Content

Courses are updated/revised/designed after interviews and/or surveys of alumni, external advisory committees, and current/past employers of graduates. It makes sense that the responses are widely varied each time a group

of diverse stakeholders are asked about what is important to them and their organizations (Schuhmann, 2010). Nonetheless, responses were collected around specific themes of knowledge of contemporary management issues (including teamwork and communication), business operations, knowledge of the technological landscape in specific industries, and creativity in problem-solving. These themes are not verified statistically because the data collected thus far is primarily anecdotal or based on advisory board recommendations.

Students entering the depressed job market after 2008 needed the ability to set themselves apart from other applicants. They learned to research what type of employees were needed at different organizations and how they could best present their skills (Intro to Engineering Management and Applied Behavioral Science), as well as interview techniques, proper email etiquette, and succeeding in a hostile work environment (Applied Behavioral Science). Students having physical evidence of their work on real-world team projects were particularly successful in obtaining internships (for existing students) and full-time employment (for graduating students). For courses including Technology Marketing, Intro to Engineering Management, Project Management, Systems Engineering, and Technology Forecasting, students leave the course with a professionally-bound project document such as a technology development strategy, marketing plan, or production flow chart illustrating their work for a client-sponsored project. These documents have been particularly successful in the job interview based on alumni and employer feedback to program faculty. It is particularly gratifying to hear from multiple students that they received their internships because they showed their interviewers projects involving their own companies. Project success is further indicated when the sponsoring company implements the student project into its corporate processes and practices. The frequency of this occurrence is nearly 100%.

The industrial advisory boards suggested new hires need actual practice in handling coordination of engineering disciplines (Systems Engineering). Students with the four required courses have the ability to blend multidisciplinary projects. Employers wanted engineers who understood marketing and cost estimation when they were designing practical solutions. They needed employees capable of designing cost-effective products (Engineering Economy, Finance and Accounting, and Supply Chain Management), as well as designing products the customer would desire (Technology Marketing).

Students wishing to start new businesses required a plethora of skills including defining user requirements (Systems Engineering), building rapid prototypes (Project Management), defining stakeholder response (Technology Forecasting/Marketing), and funding/implementing a business plan (Technology-Based Entrepreneurship). In the wake of corporate scandals, all required engineering management courses include a component on ethical decision-making that was added or expanded in 2007 to emphasize moral creativity and decision-making (Martin, 2006).

Typically, these engineering graduates started managing groups of workers/other engineers within four years (down from five years) of graduation according to post-graduation interviews of graduates and employers. This compression of the time it takes to obtain a management position seems related to the engineering management minor, but current sample responses from satisfaction surveys are low (30%). No matter the significance, students entering the management realm need to understand interviewing new hires, personality inventories, conflict resolution, performance reviews, and handling EEOC/OSHA issues (Applied Behavioral Science).

The Engineering Management capstone project is an attempt to meld the different skills together in a hands-on project to begin commercialization of a technology-based product or process. The major difference between this course and traditional engineering capstone courses is that the stakes are much higher to the client, and by extension to the student groups, because the project entails creating a commercialization strategy for a new technology. Project recommendations are presented to the clients and external stakeholders: venture capitalists, professional consultants, and other corporate leaders by the student groups. The forum for evaluation is a critique and group dialogue among the stakeholders, clients, faculty, and students. The clients are able to hear others' input and deeper rationale for the student recommendations in real time with the ability to ask and answer questions. Projects are ultimately evaluated based on their cost to the company, return on investment, human capital required, and the degree of difficulty of the implementation. The initial result of this pilot offering can be summarized by a quote by one of the serial entrepreneurs asked to judge the quality of the projects: "If it were up to me alone,

I would hire every one of these students to work in my start-ups."

Course testing in the required engineering management courses is not based on rote memorization of facts and figures. Students are presented with open-ended scenarios where they have to creatively solve an organization's problem(s) using limited resources within strict budgetary and schedule constraints. For example, a scenario states that a company trying to bid on an RFP (request for proposal included) has limited personnel, has a production facility with certain types of equipment, and must obtain appropriate suppliers for parts within a limited time frame in order to meet the requirements. Students must perform a feasibility study in a week to see whether the company should bid on the job. Test formatting is strict and professional as if the student (or student team) were reporting to a boss or employing firm. Solutions must be practical and require presenting different optionsand rationales to their client.

Conclusions

In summary, the impact of engineering management education is related to how rapidly the course content can adapt to changing workplace conditions. Institutionally, course content must be regularly reviewed, course descriptions changed, new courses added, and obsolete courses deleted. Issues taught today may be irrelevant in as little as five years. As opposed to traditional engineering disciplines, engineering management is subject to the ever-changing, global economic and technological landscapes. As alumni become increasingly connected and communicative with the program faculty, the faculty are able to respond more intentionally to recommendations on content. The uses of electronic media for communication are affording new opportunities to collect post-graduation data. This cascading increase in availability of information will allow for more formalized assessment practices.

As a result of the importance of relevance in the curriculum, the next step of curricular development is to concept map the engineering management curriculum in light of innovation leadership using the stage-gate model as a reference point. Concept mapping will assist the faculty in determining when specific concepts are presented, in what context they are presented, and how deeply those concepts are presented. Ultimately it is important to know where any weaknesses exist in the body of knowledge taught. Additional improvements in data collection will begin with responses to senior exit surveys and alumni surveys, both of which currently have very low response rates. Employer surveys are currently administered institutionally with little customization for specific programs. One improvement will be to create a more relevant survey that includes minor programs of study and gathers more relevant data for program improvement.

We propose that any engineering management program should allow for students in traditional engineering programs to be provided with the opportunity for this type of hands-on skill development. It is widely known that U.S. firms want a multifaceted, skilled worker capable of handling unique problems and not just someone to grind away calculations in a cubicle (Mechefske et al., 2005). Employers want individuals who are self-motivated, are driven, and can effectively communicate this to their work groups and supervisors (Rugarcia et al., 2000). These individuals will still need six months of skill development (a typical probationary period) in internal operations and work flow; however, the time to adapt to the corporate culture and take early leadership roles is significantly reduced. Engineers in cubicles can be outsourced at, conservatively, one-quarter the cost unless those engineers understand the economic, marketing, behavioral, production, and risk mitigation processes from a global perspective and can in-source quality products (Outsourcing Times, 2005).

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