Entrepreneurial Engineering Education

Mark Polczynski
The Technology Forge
Stanley Jaskolski
Marquette University

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Abstract The Marquette University College of Engineering is currently in the process of defining a program in Entrepreneurial Engineering. Although the program is in the early stages of planning, we believe that this description of entrepreneurial education upon which our program is based provides some useful insights into the changing nature of engineering and engineering education.

Situation analysis

Many businesses are striving to grow sales and profits while simultaneously reducing tangible assets, including high-cost, high-maintenance engineering staffs. Coupled with the continuing development of strong and highly accessible technical capabilities in so-called low-cost countries (LCCs), this trend has resulted in LCC outsourcing of manufacturing and service jobs, and now product design and development engineering jobs.[1] Compounded by increasing automation of common traditional engineering tasks, this situation significantly impacts the engineering profession as currently performed in non-LCC countries such as the US.

As the world's dependence on technology increases, there is no question that the demand for engineers is increasing. The question is: What will these engineers be doing, and where will they be doing it? With the automation and migration of traditional engineering functions to LCCs, who will engineers work for? Where will they perform this work? What functions will engineers in non-LCCs perform? And ultimately, will engineering as currently formulated remain a viable profession in non-LCCs?

Globalization has given rise to design-produce-service engines with electronically linked elements located across the globe. These virtual entities provide the capacity to produce a wide range of products and services at high quality levels and low costs, but rely heavily on a high volume and steady flow of innovative new concepts to feed the front end of these engines. With high quality and low cost global design, manufacturing, and service capacity becoming generally available, innovation in product and service offerings

becomes a key differentiator and critical success factor. Thus, as global and especially LCC capabilities and accessibility increase, innovation is becoming the world's most valuable raw material. Without this raw material, global design-produce-service engines ultimately grind to a halt. The key question now becomes: Who will generate the front-end innovations, and how will they generate them?

What-to-do vs. how-to-do-it engineering

In this rapidly evolving global business environment, an engineering role of increasingly critical importance is the generation of a continuous flow of front-end technology innovation to feed global suppliers and markets. While traditional engineering tasks, knowledge, and skills typically focus on the how-to-do-it activities associated with product and service design, manufacturing, and support, engineers are being called upon to a much greater extent to perform the what-to-do functions that drive technology innovation and fill the front-end of the design-product-service pipeline.

The fundamental difference between how-to-do-it engineering and what-to-do engineering cannot be overstressed, since it influences which engineering functions can be readily automated and/or outsourced, and therefore impacts the roles and ultimately the education of engineers in LCC and non-LCC countries.

Over a decade ago, Prahalad and Hamel[2] characterized core competencies as capabilities that are difficult for competitors to duplicate. Core competencies are seen as an organization's primary source of competitive advantage, and the areas that an organization should focus its resources and attention. Core competencies are to be protected and nurtured, and all non-core functions should be candidates for outsourcing.

The concept of core competencies significantly impacts the engineering profession. An engineering function that can be broken down into a sequence of clearly defined actions (though not necessarily simple actions) is ultimately easily duplicated, and therefore a likely and safe candidate for outsourcing. Increasing capabilities and accessibility of LCC resources make LCCs a common destination for such functions.

These functions are also prime candidates for automation.[3] The use of

combinatorial research in the design of pharmaceuticals is an example of the leading edge of this trend, and software code generation is beginning to be automated through the use of technologies such as genetic programming.

How-to-do-it engineering functions are prime candidates for reduction of repetitive tasks, so tend to be impacted heavily by automation and outsourcing. On the other hand, the innovation and intuition required by what-to-do engineering are, at this point, difficult and risky to duplicate, automate, and outsource. Thus, in the rapidly evolving world economy, what-to-do engineering is becoming a core competency, while how-to-do-it engineering is becoming non-core. As the capacity and capabilities of global virtual design-produce-service engines continue to improve, and innovation becomes the world's most valuable resource, what-to-do engineers become the highly-sought-after prospectors that discover the source of this resource.

Entrepreneurial engineering

What-to-do engineering is associated with the concept of entrepreneurial engineering (vs. traditional how-to-do-it engineering). Entrepreneurial engineering can be defined as the set of functions required to fill the front end of the design-produce-service pipeline with innovative technologies and technology-based products and services capable of providing significant growth, profitability, and sustainable competitive advantage.

Entrepreneurial engineering can be considered a subset of the more general field of entrepreneurship. While including the basic skills and knowledge required for successful entrepreneurship, entrepreneurial engineering focuses primarily on generating technology-based opportunities and the particular challenges of effectively identifying, acquiring, developing, and transferring technology into viable new products and services.

The characterization of core competencies by Prahalad and Hamel reinforces the vision of entrepreneurial engineering as a core competency. A core competency can be viewed as a complex harmonization of individual technologies and skills. Entrepreneurial engineering requires the integration of strong technical capabilities (the engineering part, and not in itself necessarily core) with the ability to advance new business opportunities (the entrepreneurial part, and also not in itself necessarily core), and thereby displays the complex harmonization characteristic of a core competency.

While it is increasingly easy and economically beneficial to migrate non-core traditional engineering tasks to LCCs, entrepreneurial engineering is not driven by the same forces. First, because of the exceedingly high value of innovation as a raw material, the cost of mining this material becomes relatively less critical. Second, and probably more importantly, entrepreneurial engineering is often best done at locations where resulting products and services are ultimately consumed. While new products being sold in a particular region need not necessarily be designed, manufactured, and serviced locally, innovations conceived in a particular area may better meet local customer needs. Innovation is often best performed where the users of the innovation reside; knowing what to do often depends on where you are.

Coupling the relative cost insensitivity of front-end innovation with the benefit of local innovation content, entrepreneurial engineering represents an increasingly important role for engineers throughout the world and a viable profession for engineers in non-LCCs in particular. From certain perspectives, current economic trends can paint a relatively pessimistic picture for some elements of the global environment, and especially for engineers in non-LCCs performing traditional functions. But from other perspectives, the growth of global markets and global supplier bases can make this a golden age of entrepreneurship, with entrepreneurial engineering being a key contributing factor.[4]

Entrepreneurial engineering education

On-the-job training provides a common source of entrepreneurial engineering education. Engineers working for companies may be given expanding responsibilities that expose them to innovative and entrepreneurial activities, with the associated knowledge, skills, and experience often being picked up anecdotally. Selected fast-track performers may be provided with specific development opportunities involving entrepreneurship. And, of course, an emerging engineer entrepreneur may also get direct on-the-job training by starting up a new business.

Formal education provides an augmentation or alternative to on-the-job entrepreneurial training. Of course, entrepreneurship does not constitute a new specialty area in education. Entrepreneurship is commonly taught through business schools at the graduate level, but engineering school graduate

programs in entrepreneurial engineering, and most recently undergraduate programs in this area, are becoming well-established.

The field of entrepreneurial engineering (vs. entrepreneurship in general) acknowledges the high-leverage role that engineers play in generating viable high-value business opportunities, the distinctive needs of engineers functioning in an entrepreneurial environment, and the fact that traditional engineering curricula tend to focus on how-to-do-it technical knowledge and skills, with little or no emphasis on entrepreneurship.

Undergraduate entrepreneurial engineering programs typically augment an engineering student's fundamental technical courses with courses and experiences essential to entrepreneurship, such as finance and accounting, teaming and leadership, innovation and intellectual property generation, and cultural diversity. Graduate-level engineering programs (vs. business school programs) often integrate entrepreneur-oriented courses and projects with programs in engineering management.

Offering entrepreneurial engineering as a formal program of study at the undergraduate level introduces the art and science of entrepreneurship to the student at a formative period in their engineering education, and also creates an application context for a student's technology-oriented courses. Close coupling of course work with entrepreneurial team projects produces a safe (low-risk) environment for obtaining direct experience in entrepreneurial ventures. Conducting this education in a culturally diverse environment increases comfort and effectiveness when students enter the global entrepreneurial community, and also expands the student's global network of contacts.

Offering an engineering program in entrepreneurship at the graduate level allows greater focus on aspects of entrepreneurship characteristic of technology-based new product and service opportunities. Thus, while a business school entrepreneurial program might focus on specific elements such as resource acquisition and leveraging, financial risk mitigation and management, and design of operations models, an engineering-based program might focus on strategic technology planning and development processes, new concept ideation, technology needs assessment, technology roadmapping, and intellectual property generation (vs. IP protection).

Further distinction between entrepreneurship and entrepreneurial engineering is valuable at this point. The fundamental model of entrepreneurship referenced here assumes that entrepreneurial entities will not necessarily incorporate design, production, and service functions, since these can often be readily outsourced. Thus, intimate understanding of these functions is not core to entrepreneurial engineering per se, though it may be to entrepreneurship in a broader sense. Furthermore, it is assumed that engineers will typically be members of teams (real or virtual) that possess the full range and depth of entrepreneurial skills and knowledge. In this sense, the goal of entrepreneurial engineering is to enable engineers to participate comfortably and effectively on entrepreneurial teams while focusing on identification, acquisition, development, and transfer of technology into innovative new products and services (i.e., filling the front end of the pipeline vs. building and running the pipeline).

Some engineering schools are characterized as research institutions, while others consider teaching to be a primary function. Entrepreneurial engineering can have a place at both types of institution. For institutions that teach a profession (e.g., law, medicine, engineering), there is a basic assumption that most graduates will actually practice the profession being taught, and therefore a presumed responsibility to adequately prepare students for employment. The rising importance of entrepreneurial engineering makes this field clearly relevant to teaching institutions. Since entrepreneurial engineering programs typically include team experience involving actual entrepreneurial opportunities, the relevance of entrepreneurial engineering for a research institution lies in enhancing the institution's ability to take the fruits of their work to products and customers (and, incidentally, for both types of institution, to the bank).

Yet another element to entrepreneurial engineering education must be considered. Driven in part by automation and migration of functions, the era of twenty-year tenure-track engineering employment is over. In response to this, engineers must become self-sufficient and self-reliant business entities, regardless of what functions they perform, who they work for, or where they work. As engineers move through their career, they must be prepared to hit the ground running as their environment changes. To maintain viable careers, engineers would do well to view themselves as one-person entrepreneurial

businesses. Entrepreneurial engineering education should foster this vision of personal entrepreneurship.

Key linkages

The need for entrepreneurial engineering is associated with a need to create and maintain viable, attractive, high-value employment through the generation of technology-based business opportunities.[5] While education directed at this field can contribute to this goal, the overall solutions to the complex fundamental problems involved in achieving this goal are holistic in nature. This means that an entrepreneurial engineering program should have strong linkages to other solution elements. Linkages to (and among) the following entities should be included: business, investors, other educational institutions, and entrepreneurial individuals.

Entrepreneurial engineering programs frequently involve direct experience developing entrepreneurial opportunities. Strong linkages to business are needed to generate relevant project opportunities and to provide potential destinations for project outputs. For those projects that generate viable new opportunities but do not migrate naturally to business partners, access to investors can be key to moving the opportunities out of the program. The rise of so-called angel investment can be a significant boon to entrepreneurial engineering, and links to angel networks can enhance entrepreneurial engineering programs.[6] Because of the multi-disciplinary elements of entrepreneurial engineering, strong linkages to other colleges are necessary for an engineering school to create a comprehensive entrepreneurial engineering curriculum. Ideally, these educational links reach upstream to secondary and even primary schools, thus allowing complementary augmentation of science, technology, engineering, and mathematics (so-called STEM) education at these levels.

In addition to these institution-oriented links, links to individual entrepreneurs are also critical for entrepreneurial programs, both as a source of students and as a source of innovation. While access to capital is often seen as the primary impediment to entrepreneurship, viable innovations of sufficient magnitude to move the needle are perhaps not as readily available as commonly thought. An

entrepreneurial engineering program must have links to individuals capable of seeding the system.

All four of these linkages must be considered in both a local and global context. Local links to business, investors, educational institutions, and entrepreneurs can create a powerful local entrepreneurial community. Such a community can have a significant impact on solving local economic problems caused by factors such as job migration. But globalization is a key driver behind entrepreneurial engineering, so programs in this area should be conducted in a global context. Global business, investor, educational, and entrepreneur linkages must be stimulated.

Summary

Entrepreneurial engineering is a function of growing importance, and can have an especially significant impact on the engineering profession where automation and global migration of traditional engineering functions are occurring. Entrepreneurial engineers focus on the what-to-do functions associated with filling the front end of the expanding global supplier/customer pipeline. In this capacity, entrepreneurial engineering represents a difficult-to-outsource core competency. Undergraduate and graduate programs in this field can improve the quality and rate of development of entrepreneurial engineers. Entrepreneurial engineering education (vs. general or business-oriented entrepreneurship) acknowledges the high-leverage role that engineers play in generating viable high-value business opportunities, the distinctive needs of engineers functioning in an entrepreneurial environment, and the fact that traditional engineering curricula tend to be focused on how-to-do-it technical knowledge and skills, with little or no emphasis on entrepreneurship. Entrepreneurial engineering programs frequently include multi-disciplinary courseware and project activities focused on new opportunity generation conducted in a culturally-diverse environment. Strong linkages to businesses, investors, educational institutions, and individual entrepreneurs at local and global levels constitute a critical success factor.

Footnotes

1 The shift to electronic documentation, model-based product design, and the dramatic spread of the Internet have had the combined effect of vastly improving access to global engineering resources, thus accelerating the shift toward offshoring of

engineering functions.

2 Prahalad, C.K. and G. Hamel, "The Core Competencies of the Corporation," Harvard Business Review, 68 (1990): 79-91.

3 In the limit, outsourcing of engineering to LCCs is the equivalent of organic automation. As technology advances and the capabilities and availability of LCC engineers improves, the choice between the two approaches is often driven primarily by which approach best meets cost, quality, and delivery requirements.

4 The booklet The Engineer of 2020 (National Academies Press, 2002) provides and excellent general overview of the situation, and an especially applicable prediction related to the importance of local entrepreneurship. Citing the rise of customerization (mass customization based on individual preferences), the authors observe that "present concerns about outsourcing of low-wage, mass production manufacturing jobs may be misplaced. Instead, the concern should be about creating a workforce and business environment that prospers in a mass-production-less economy." Entrepreneurial engineers would be a key element of such an economy.

5 In this sense, creation of new jobs and new businesses can be a principal outcome of an entrepreneurial engineering program, and also a key (albeit difficult to quantify) metric for the program.

6 Recent interest in alumni-based angel networks could have a major impact on entrepreneurial engineering programs.