The Impact of Technology and Globalization on the Engineering Profession and Education

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Abstract: *The world needs more engineers, but these engineers must be prepared to function effectively in rapidly-changing global and technical environments. Global changes in technology and society are altering the traditional concept of what it means to be an engineer. This presentation provides an overview of drivers and trends impacting the engineering profession. The concepts summarized in this presentation can aid: 1) practicing and student engineers in planning an educational program that will support a sustainable career; 2) technology-driven industries in preparing effective human resource plans, and 3) educational institutions in evolving curricula suited to the needs of their student and industry customers.*

Introduction

The world needs more engineers, but these engineers must be prepared to function effectively in rapidly-changing global and technical environments. Global changes in technology and society are altering the traditional concept of what it means to be an engineer. This presentation provides an overview of four drivers that are impacting the engineering profession:

- Engineer-In-A-Box: the automation of engineering functions,
- Engineer-As-Innovator: mining the word's most valuable resource,
- Engineer-As-Contracting-Company: the end of tenure track employment,
- Engineer-As-Self-Directed-Lifetime-Learner: taking responsibility for continuous self-re-invention.

The presentation also addresses four trends that derive from these drivers:

- Engineer-As-Explorer: invention vs. discovery,
- Engineer-As-Entrepreneur: filling the front end of the innovation pipeline,
- Classroom-As-Training-Ground: hitting the ground running,
- Classroom-As-Melting-Pot: delighting customers vs. building infrastructure.

The concepts summarized in this presentation can aid the following stakeholder groups to better understand their changing roles and responsibilities:

- Practicing and student engineers planning an educational program that will support a sustainable career in engineering,
- Technology-driven industries devising means to effectively utilize engineering resources,
- Educational institutions evolving curricula suited to the needs of their student and industry customers.

Drivers

A number of factors are driving changes in the engineering profession. Here, four particular drivers are reviewed.

Driver 1: Engineer-In-A-Box

Two major drivers for industry today are the need to continuously grow sales and profits, and to continuously reduce tangible assets such as buildings, machinery, and staff, including high-cost engineering resources. The constant pressure to do more with less has led, in turn, to outsourcing of technical functions that were once considered core competences, and to the continued automation of a wide variety of engineering functions. Product design and development is following the now-familiar path of manufacturing and services, accompanied by other high-level functions such as medical X-ray diagnosis and patent preparation.

In a sense, outsourcing and automation are opposite sides of the same coin. In general, functions which can be broken down into a sequence of repetitive and relatively predictable operations (though not necessarily a simple set of operations) are prime candidates for outsourcing and automation. Whether a function is performed within an organization or is outsourced, or whether it is performed by a human or an automaton is becoming primarily a matter of cost vs. quality, with this ratio being in a constant state of flux for various particular outsourcing/automation scenarios. Ultimately, the ability to rapidly and accurately perform this type of evaluation constitutes a core competitive advantage for an organization.

Because of the constant pressure to do more with less, outsourcing of engineering functions will be a primary driver for the engineering profession for the foreseeable future. Any engineering function that *can* be reduced to a sequence of repetitive operations *will* follow the outsourcing path. Further, as technology continues to advance at exponential rates, organizations will "outsource" human functions (regardless of where those humans may have resided) to machines which are probably owned by other organizations, thus satisfying the need to reduce tangible assets. (Where this cascading of outsourcing of tangible assets ends is beyond the scope of this discussion). A number of engineering functions have or are following this path, including circuit board and now integrated circuit layout, and software programming through the application of technologies such as genetic programming.

If we extrapolate on the drivers referenced above, then it appears that many human engineers (regardless of where they work or who they work for) will ultimately be replaced by *table-top engineer-in-a-box systems*. These machines will be capable of designing products to specification, and then virtually prototyping and proving out designs via system simulation. In fact, this move is already underway in areas such as combinatorial materials research, which unite automated design of new materials with miniaturized scientific tests, automated specimen fabrication, and computerized analysis. A notable current application of this approach is the development of massive "libraries" of potentially viable drugs by pharmaceutical companies.

Driver 2: Engineer As Innovator

The drive to reduce tangible assets that impacts many large organizations has a significant positive impact on small organizations, and ultimately on the individual innovator. This driver stimulates the creation of highly-competent, highly-accessible external sources of engineering functions, and ultimately to table-top engineer-in-a-box systems. But once these sources exist, they can be utilized by anyone with the funds to access the source for the period needed to perform a particular function. Thus, the engineer-in-a-box is a highly democratizing factor. In essence, anyone anywhere can be a virtual design engineer, with in-depth knowledge of the science and technology behind the underlying engineering functions no longer being a barrier to entry.

But of course, such systems work on a very strict garbage-in, garbage-out principle. (Interestingly, one of the major problems encountered by organizations utilizing currently primarily human-staffed engineering outsourcing services is that these services do, indeed, give them *exactly* what they asked for!) In this scenario, the ability to ask for the right thing and to completely and correctly describe that right thing become critical success factors.

Here, we make a distinction between traditional *how-to-do-it* engineering, as performed by what we

could term *inventors*, and *what-to-do* engineering performed by *innovators*. Some of the core competencies of the engineer-as-innovator include:

- What new, unique things people will actually buy,
- What automated design systems can actually design,
- Who best can design and produce these things,
- How to convert customer wants/needs into a complete, concise product specifications that will result in viable products.

It is important to note that, to a large degree, the engineer-in-a-box and the engineer-as-innovator are mutually-enabling functions, and that we can expect the development of both functions to occur in lock-step.

Driver 3: Engineer As Contracting Company

In a simplistic sense, the primary driver behind outsourcing of any function is fundamentally the time value of money. Organizations want exactly the resources they need to do exactly the task that needs to be done for shortest period of time at the best cost/quality level. Obviously, this requirement and the general solution of outsourcing have always been with us. What has changed is the increased importance of the time value of money and the capabilities and accessibility of external sources, which has the effect of continuously increasing the number of functions on the outsourcing block. (The issue of what remains inside an organization if everything is open to outsourcing is touched upon later in this discussion).

The engineer-as-innovator function outlined above is not immune to outsourcing. A desirable scenario for organizations involved in new product/service development would be to hire and pay product development teams by-the-job. In the limit, teams form in response to specific needs, perform the required tasks, and then disband. In this scenario, teams must be self-sufficient, and must "hit the ground running". Ideal team members include individuals with technical, marketing, and financial knowledge, skills, and experience, and include an engineer-as-innovator. The team also has access to all the required tools, including access to engineer-in-a-box systems.

Given the continued globalization of customer and supplier bases, we can see this situation driving creation of global product development teams consisting of individual "virtual contractors" packaging products customized for local consumption. In the limit, the individual team members may never meet in person, and may never be employees of a single company. In this scenario, global and local cultural awareness is a critical success factor for team members.

In this environment, it is beneficial for engineers to view themselves as *portable, self-sufficient contracting companies*. While they may spend a portion of their career being an "owned" resource by a particular company, they should view themselves as being self-employed. A key competency for this mode of operation is the ability to anticipate and queue-up future assignments, teams, and employers.

Driver 4: Engineer As Self-Directed Lifetime Learner

Obviously, not all functions or people in an organization will be outsourced, and organizations can be expected to invest heavily in career development and knowledge, skills, and experience enhancement for high-potential fast-track employees destined for leadership positions (as evidenced by the A/B/C – advance/tolerate/"manage out" employee categorization scheme now in vogue).

So, where does that leave the rest of the engineering workforce? In the past, engineers often acquired and enhanced skills (especially non-technical skills) through on-the-job osmosis over years of working on a variety of projects. But in the future, opportunities to acquire new skills while working on projects will be limited. Career development will consist of getting on the *right* project teams, but engineers will need to already have the right skills to get on the right projects, and employers won't invest heavily in re-treading worn-out engineers, since it's cheaper and easier to hire new ones or outsource functions. This is compatible with the drive to reduce investment in tangible assets.

In this environment new and incumbent engineers will be personally responsible for identifying and pursuing off-line skills enhancement and career development opportunities, giving rise to the concept of *engineer-as-self-directed-lifetime-learner*. In essence, organizations will "outsource" career development and capabilities enhancement to the employees themselves.

Trends

These four drivers tend to generate a number of trends, four of which are outlined here.

Trend 1: Engineer As Explorer

Previously, we described the shift from how-to-do-it engineering to what-to-do engineering as a move to engineer-as-innovator. Similarly, the *invention* paradigm upon which engineering education is currently based will be augmented by a *discovery* paradigm. While engineer-in-a-box systems take on the burden of inventing, engineers will spend more time exploring multitudes of potentially viable products and services, and discovering the most appropriate configurations for these products and services. The resulting product and technology maps (to extend the metaphor) will serve as specifications for automated design systems. Again, combinatorial materials research provides a strong indicator for this trend.

While some organization will continue to heavily emphasize basic hard science related to how and why things work, this type of activity will be ultimately limited to a smaller engineering population involved in developing engineer-in-a-box systems. Consider, by analogy, the number of technologists once employed in designing and building application-specific electronic circuitry vs. the number now employed developing software based on object-oriented re-usable code for execution on general-purpose hardware. (Does anyone actually know how a microprocessor works any more?)

Replacing this traditional mode of operation will be an increased emphasis on employing and educating *engineer explorers (vs. inventors) capable of discovering vast new territories for* *innovation*. Education for these engineers will emphasize identifying relevant, viable what-to-do opportunities, and learning how to appropriately apply engineer-in-a-box systems to realize these opportunities.

Trend 2: Engineer as Entrepreneur

In the global economy of the future, highly capable and highly available engineering and manufacturing resources will be readily and commonly available. This situation leads to a condition where virtually any individual innovator will be able to have virtually anything designed, produced, and supported at low cost and high quality for customers located around the globe. In this environment, the capacity to determine exactly what should be made becomes the most valuable resource in the world.

A key function of what we term here the entrepreneurial engineer, operating as a member of a virtual innovation engine, will be to rapidly and continuously fill the front end of the virtual global design-manufacture-service pipeline with innovations that will fuel local and global economies (Exhibit 1). Four essential functions differentiate the entrepreneurial engineer: 1) the ability to envision and reduce to practice unique technology-based solutions; 2) the ability to effectively transfer technology; 3) the ability to assess and enhance the commercial viability of technology-based products and services; and 4) the ability to maintain an initial competitive advantage provided by a technology [1]. Entrepreneurial engineers will be heavily involved in answering questions such as:

- What to invent?
- Why should it be invented?
- Who will want it invented?
- What to do with the invention after it is invented?
- How to make money on the invention?

Trend 3: Classroom as Training Ground

There is considerable concern about the need for more and better-educated engineers. But based on the preceding views, the basic nature of engineering is changing in a way that makes engineering an increasingly critical function. In many ways, engineers have played a relatively passive role in many organizations. Experts at how-to-do-it, engineers typically accept problems defined by others. While creative and pro-active in searching for appropriate solutions, this is still a fundamentally reactive mode.

In the future, acting as innovator, explorer, and entrepreneur, what-to-do engineers will have a much greater role in defining directions, developing strategies, and similar pro-active organizational functions. Thus, ironically, development of engineer-in-a-box systems actually drives up the requirements for being a good human engineer. At the same time, engineers will be personally responsible for meeting these requirements.

Educational institutions of many different types are in a position to provide the technical training to evolve engineers into explorers and innovators, and the business training to convert engineers into entrepreneurs. These institutions will see a growing cadre of lifetime-learners added to their entry-level student rolls. These institutions will need to provide knowledge, skills, and most of all, direct hands-on experience. These institutions will provide *"safe zone" training grounds* where engineers can practice developing new technical and business skills without risking harmful effects to "real" projects on which they are working, or more importantly from the perspective of engineer-as contractor, to their own career.

In this environment, educational institutions will augment standard information transfer education with entrepreneurial team projects that are equivalent to actual work environments. Engineers will be capable of immediately and effectively applying new technical and business knowledge and skills as they enter the work force or join entrepreneurial teams. An interesting side-effect of this trend is that entrepreneurial team projects associated with educational institutions will serve an increasingly important role as new business incubators.

Trend 4: Classroom as Melting Pot

It is possible to divide the global market landscape into two functional territories: delighting customers, and building infrastructure. Organizations serving primarily the first territory typically focus engineering efforts on improving factors such as functionality, convenience, and quality of products and services, and on adding attractive and distinctive stylistic elements to products. Engineering (formal or informal) of products destined for the second territory focus primarily on meeting basic human needs (vs. fabricated wants) in the most expeditious manner possible.

Historically, typical student populations in institutions of higher education are drawn primarily from the first environment, with students from the second environment commonly being under-represented. It has been common for the curricula of engineering institutions (at least in the U.S.) to reflect this demographic constituency, i.e., curricula are typically oriented toward teaching how-to-do-it skills that make want-based products and services bigger, faster, and shinier, i.e., products that delight customers.

On the other hand, engineering as applied to the building infrastructure territory founded on meeting basic human needs represents a large and largely un-tapped entrepreneurial potential and responsibility for engineering education institutions. In order to serve this environment, these institutions need to pro-actively recruit students from under-represented cultural, racial, economic, and geographic groups. Further, curricula need to be modified to represent minimalist approaches as well as high-tech solutions. Finally, these institutions must pro-actively strive to become melting pots that prepare entrepreneurs to effectively work into all types of economic environments. The primary motivators for these changes are:

- This significantly expands the pool of perspective students,
- This prepares students for the global entrepreneurial environment that is driving changes in the engineering profession.
- This is the *right* thing to do.

Responses

Based on the drivers and trends outlined above, potential responses for employers, engineers, and engineering educational institutions can be projected.

Employers:

The majority of the engineers employed by a company will be parts of (usually outsourced) virtual global design-manufacture-service pipelines, and will be focused on generating products and services as specified by their employer, and on optimizing the pipeline itself (how-to-do-it). A smaller number of engineers will reside in entrepreneurial teams (also typically outsourced) focused on defining specific needs of individual customers and turning these needs into specifications for new, commercially-viable products and services (what-to-do).

As inferred from Exhibit 1, the ultimate outsourced company contains only two elements: strong channels to customers and suppliers, and intellectual property. The drivers and trends outlined above have significant impact on both of these core competences.

Currently, successful organizations tend to be heavily customer-oriented, with strong channels to market being a critical success factor. In the future, links to virtual global design-manufacture-service pipelines will be equally critical, and guarded and cultivated with equal fervor. Given the value of innovation as a raw material, establishing and maintaining equivalent links to virtual innovation engines will be even more critical.

While generally recognized as becoming increasingly important, intellectual property becomes both a strength and a potential source of weakness in this scenario. First, in many cases intellectual property will originate outside of a company. Second, in many cases it will be sent outside of the company for transfer into products and services. Thus, securing intellectual property becomes as important as (and, indeed, becomes synonymous with) securing channels to suppliers and customers.

Engineers:

Due to the drivers and trends outlined above, we may well be entering the golden age of innovation. Global design-manufacture-service pipelines will allow virtually anything to be developed and offered at low cost and high quality levels, as long as individuals like entrepreneurial engineers continue to provide an adequate flow of the innovations required to drive these pipelines.

However, as essential as engineers are to this system, an engineer can expect to encounter significant hurdles to achieving a viable long-term profession in engineering. There are several reasons for this, including the following.

While the demand for what-to-do engineers is already rising, most engineers achieve this level of functionality via how-to-do-it engineering assignments. But these are the types of assignments that are being outsourced or automated. The author's recent discussions with employers of engineers indicate a strong need for project leaders, but limited entry-level openings. So, how will engineers entering the work force in environments such as this secure entry-level assignments that will lead to project leadership positions? This will pose a great challenge for new engineers.

The question is a bit different for practicing engineers. As outsourcing and automation expand, the up-or-out approach more common for non-technical functions will apply more strongly to technical tracks. In the future, "up" will not typically be achieved through increased technical capabilities, but capabilities associated with the innovator-explorer-entrepreneur models outlines above. Obtaining skills in these soft disciplines, i.e., learning to operate as a one-person engineering contract company, will be a challenge for practicing engineers. (Of course, the MBA has been the traditional ticket for engineers seeking to move up the *management* track, but the argument here refers to maintaining a viable *engineering* profession.)

Clearly, shifting to a self-directed lifetime learner mode is part of the solution to the above challenges. But engineers have tended to rely heavily on employers for career direction and training support in their pursuit of lifetime learning. The key challenge here, then, is to become s*elf-directed* in pursuit of new knowledge, skills, and experience. In many cases, an employer will have not only little interest in advancing an individual engineer's career, but will have no clear idea as to what direction career development and training should proceed. In the future, no one may know the answer to this better than the engineer. This is the challenge of being a *self-directed* lifetime learner.

***Technical Institutions**:*

The need for new kinds of engineers and the need for lifelong learning provide great opportunities for technical institutions. But these institutions face several challenges in leveraging these opportunities.

Currently, the majority of curricula at technical institutions are focused on teaching how-to-do-it functions. More emphasis is now being placed on issues such as general approaches to problem-solving, etc., but by-and-large, technical institutions are still graduating primarily how-to-do-it engineers. Incorporating curricular and extra-curricular elements that provide knowledge, skills, and hands-on experience in what-to-do-engineering will be a major challenge for many technical institutions. The customers for the product of engineering institutions demand that the engineers that they hire (at whatever level and function) need to be able to hit the ground running. To remain competitive, a technical institution must meet this need.

The need to turn classrooms into melting pots has been presented. This offers two challenges to technical institutions. First, student bodies in many institutions do not contain a cross-section of origins. (Forget MIT, think Beijing Institute of Technology, or India Institute of Technology). In order to adequately prepare engineers, these institutions will need to pro-actively work to correct this situation. In institutions that have a better cross-section of students, these students are typically viewed as heads to be filled with knowledge, with little pro-active work to create the needed melting-pot environment in the classroom or institution [2]. Both situations pose great challenges to these institutions.

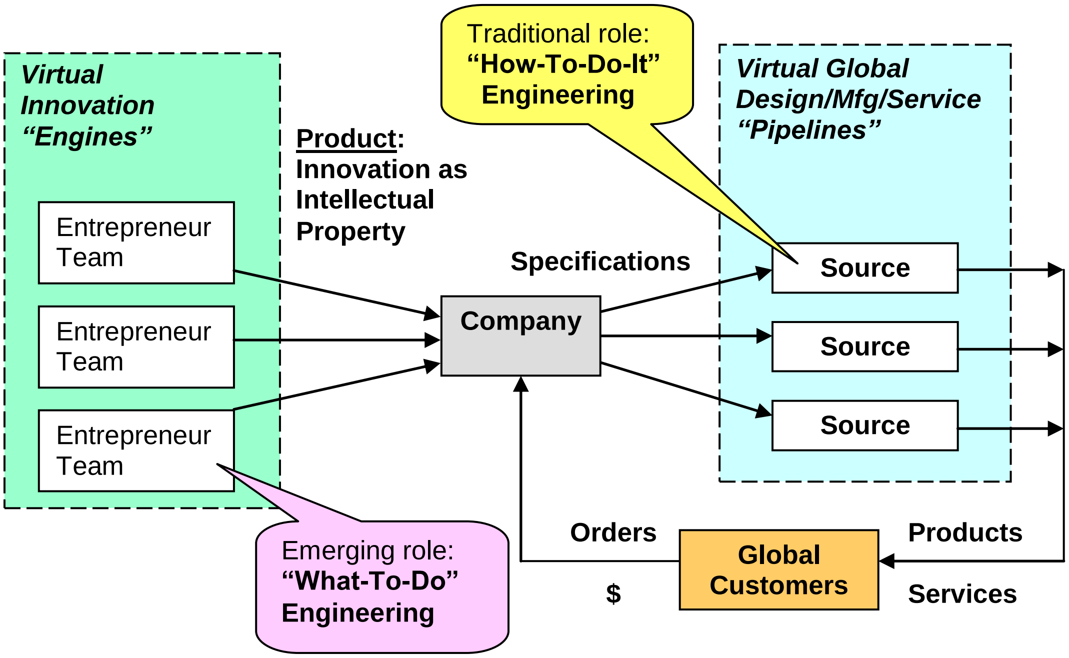
An associated challenge for technical institutions is characterized by the concept that "the Third World may be in your back yard". Expanding the demographic cross-section includes expansion of financially as well as culturally and geographically "remote" students. Further, in the spirit of innovation, exploration, and entrepreneurship, technical institutions must become pro-active drivers of local entrepreneurship and contributors to the local economy (beyond simply employing locals).

As with industry, education is constantly being required to do more with less. It is critical for technical institutions to understand that all the factors that drive industry to outsourcing and automation of how-to-do-it functions apply to the educational industry as well [3]. Fortunately, the accumulation of industrial experience in reducing cost and improving quality through these means provides models for success that can be adapted for education. As with industry, effective employment of these means can lead to success or failure of an institution.

Conclusion

In the spirit of scenario analysis, many of the positions presented here are purposely extreme. For example, a rather dismal and cold-hearted view is painted of how organizations address career development for engineers. Obviously, many organizations have excellent employee career development and training programs. But certainly an equal number do not. The issue here is which direction the drivers and trends noted are pushing employers, engineers, and educational institutions. Above all, views such as "*my* job will never be eliminated!" must be questioned. Considering the challenges posed above and devising appropriate personal responses is the essence of being a self-directed lifetime learner.

Exhibit 1: Global Engineering Environment



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