

**The Impact of Globalization on
Engineering Education in the United States**

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Abstract:

An internal project was recently taken on by the University of Illinois, College of Engineering to understand the changing nature of engineering in the United States due to globalization and technology. In-depth interviews with high ranking technology executives across a wide range of industries were conducted. Key questions were designed to understand what skills will be required of engineering roles likely to remain, or grow in demand, within the US as well as understand what job functions are likely to be outsourced. A framework outlined by Steele [13] was used for analysis of the data. Findings include the observation that differing organization typologies prioritize a relatively common list of skill requirements in different ways. These skills include knowledge of engineering theory, holistic design skills, interdisciplinary skill, softer people-oriented skills, project-based experiences and critical thinking regarding integration processes.

1. Introduction

Anecdotal observation leads one to conclude that the nature of the engineering profession in the United States has measurably changed over the past several decades and, that it is likely to continue to change into the foreseeable future. For example, a large proportion of manufacturing engineering positions have migrated to lower labor rate areas such as Asia, Eastern Europe and Mexico [12]. Similarly, numerous software development and customer service centers have been established in India to address needs once fulfilled by the domestic US workforce [14]. Globalization has resulted in a wide range of jobs moving abroad due to related factors which include (1) low cost of overseas skilled workers, (2) the availability of information technology and the Internet's capability to allow global workforces, (3) the recent trend of corporations to become more global in nature.

The impacts of globalization on the engineering profession consequently creates a challenge to understand what it means to be an engineer in the 21st century global economy and how best to prepare the engineers of the future. As educators, we must prepare engineers with the skills needed to drive and benefit from these changes. In order to learn how best to prepare the engineers of tomorrow we must understand the future nature of the engineering profession. By understanding new skills that will be required of business and industry we can add to the knowledge base of engineering education and better prepare the engineers of tomorrow.

In the following pages the literature surrounding changes in engineering education will be discussed. Second, Steele's [13] framework of organizational typologies will be presented. Third, the methods used for collection of qualitative data from high ranking technology officers in leading engineering organizations will be provided. Fourth, the results of the research are presented and analyzed using Steele's framework. The challenges of globalization on engineering are contrasted with new opportunities expected from technology innovation, services, and the development of complex systems. Finally, limitations of the study will be addressed.

2. Literature Review

Effective engineers must possess a broad range of knowledge and skills going beyond the technical knowledge of an individual's native discipline [11]. Historically engineering curricula have required students to learn often unconnected, separate courses whose relationship is

unrecognized until late in undergraduate education [3]. Traditional engineering curricula present a set a topics, or collection of courses, that students need to know. Traditional education in engineering could be described, for the most part, as linear. For example, students first learn math and science before being *allowed* to frame an engineering problem, let alone build something [3].

2.1 Call for Change in Engineering Education

A host of scholars have called for dramatic change in engineering education. Bordogna et al. [3] called for *a more comprehensive view*, focusing on the development of broader and connected educational experiences. These scholars placed emphasis on developing the capability for lifelong learning and better engaging the individual through the educational process among others. More recently, a broad process of *integrated learning* has been described in response to the changing needs in engineering education [11]. Integrated learning stresses going beyond the technical content in undergraduate engineering. The scholars describe the objectives of integrated learning as improved communication skills, increased design content, lifelong learning and team skills, and an enhanced awareness of management as well as other disciplines. A number of techniques can be applied to curricula in order meet the grand objectives of integrated learning [10]. These are described as team based and project learning, just-in-time delivery of theory, improved facilities or plazas, and the application of experimental learning.

2.2 Emphasis on Experimental or Constructivist Learning

Attention has also been given to new approaches to improve learning including project based curricula. Scholars have indicated learning is most effective when the student is active, as opposed to passive, in the learning process [7, 8, 11]. This view is consistent with the premise that through our experiences we construct our own understanding of the world we live in, sometimes referred to as constructivist learning. Constructivists such as Dewey [6] indicate learning is constructed and that knowledge is achieved through participation in activities. The constructivist theory stresses *hands on learning* or *learning by doing*.

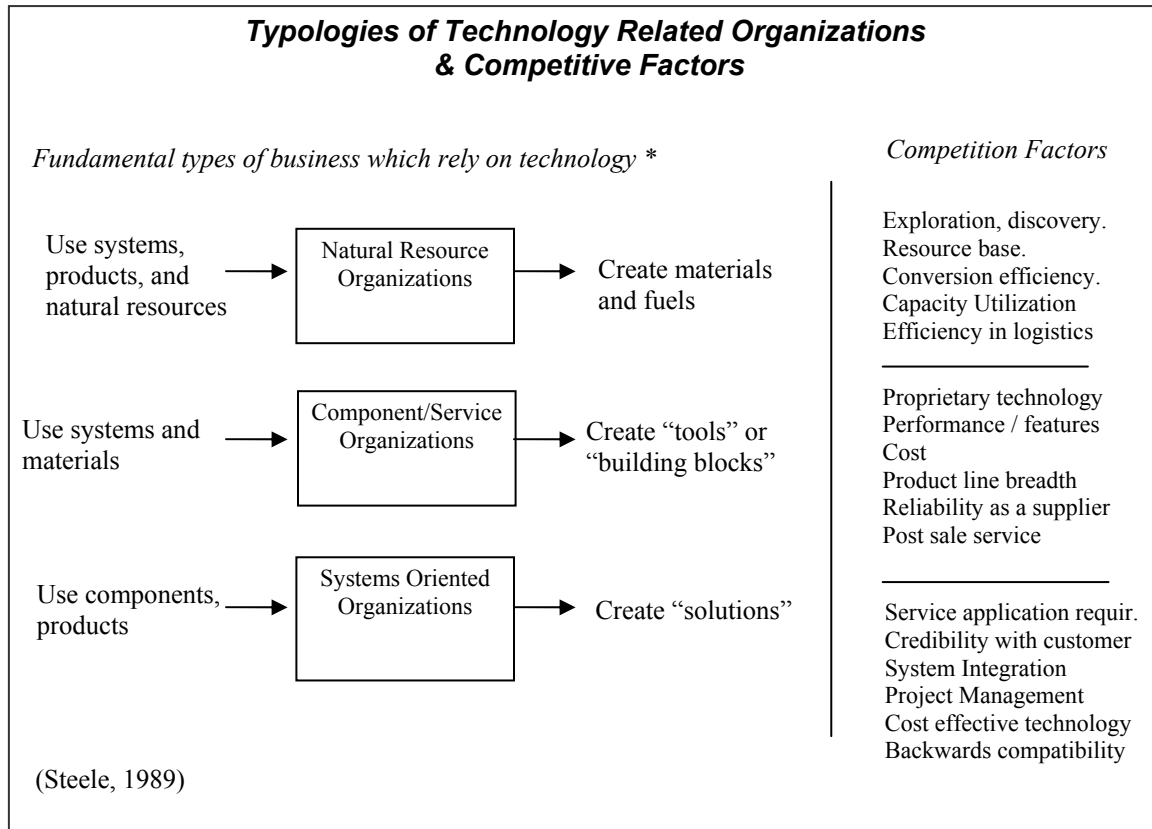
2.3 Lack of Empirical Literature

Upon review of the engineering education literature there is a dearth of empirical research on the changing needs in engineering education as a whole. Scholars note profound changes in society and technology [9] that in-turn greatly affect engineering. Changes in curricula such as increasing the breath of education and working in multidisciplinary teams [1] are commonly prescribed in the reviewed literature. Although a number of changes have been suggested, very little empirical evidence is available on the changing role of the engineer or the success of varying interventions.

3. Theoretical Framework

Although the landscape of the engineering profession is changing as a whole, the impact will naturally vary based on the organization type. Steele [13] indicated differing business orientations that correspondingly make a difference in their needs and how competitive advantage is gained. Features inherent in the nature of a business determines many of the constraints under which a business must operate and set priorities. They affect the time horizon and the pace of the business, and they strongly influence the modes of competition chosen. Certainly, they affect technology and how it is managed. The ways organizations compete drive their needs. Steele suggested basic building blocks of the competitive equation which will be used in order to analyze differing organizational engineering and technology needs as well as the way they compete. These differing organization typologies include natural resource based, component/service oriented, and systems oriented organizations. A comparison of the three typologies is presented in Figure 1.

Figure 1



2.1 Natural Resource Based Organizations

As one would expect, natural resource based organizations’ principle business is locating, extracting, and refining raw materials. Their interest in technology centers in exploration and discovery. The ultimate user is somewhat remote and their specific needs are practically invisible. Competencies focus on the following:

- Effectiveness of discovery,
- Quality and magnitude of the resource based
- Conversion efficiency.

Examples of these companies include mining companies such as Alcoa, BHP Billiton, Umicore, WMC Resources; and energy companies such as BP Plc, ChevronTexaco Corp., ExxonMobil Corporation, Royal Dutch/Shell Group, and TOTAL S.A. (listed alphabetically).

2.2 Component/Service Orientated Organizations

Component/service orientated organizations emphasize the value of the product attributes they offer a customer, which are primarily based on special technology or low cost manufacturing. These organizations create products, tools, or building blocks used in larger systems. Although they warrant their products meet promised performance and price; they do not focus on the integration of larger systems to meet the ultimate customer's need. These companies generally use innovation as a basis for competition. They are concerned with appropriating intellectual property and technical advance. The ordered list of competitive factors for these types of companies includes:

- Ability to create proprietary technology
- Performance and features of products
- Cost of production and distribution
- Product line breadth
- Reliability as a supplier

They are likely to attempt to increase their value add by vertical integration. This may be by backwards integration into suppliers or investments in core competencies of their own R&D. Examples of these companies may include portions of Intel and other chip companies, the traditional view of GE, or electronic device and product makers such as HP/Compaq.

2.3 Systems Orientated Organizations

Systems orientated organizations focus on serving the customer's needs by knowing and understanding the customer. They offer solutions, not just capabilities. Instead of focusing on components, they place the highest value on knowing the customer. In general they regard technology as something one can acquire while the critical ingredient is knowledge of the system. They view vertical integration as limiting flexibility, making one vulnerable to shifts in the business environment. These companies compete on the basis of the following:

- Understanding complex needs of customers and building good customer relationships
- Efficient system integration and project management processes
- Low cost sourcing of components and base technologies

Examples of systems companies include conglomerates such as Siemens, IBM, Toshiba; consulting firms like Accenture; construction equipment and automobile manufactures including Ford, GM, Caterpillar, and John Deere.

3. Methods

Within this framework, we chose to examine technology based needs in order to respond to the research question. Interviews took place with high ranking technology executives, usually falling under the title of Chief Technology Officer (CTO), during the Fall of 2003. World class organizations were targeted across a broad range of industry segments most of which reside in the Fortune 100. An interview guide was created and used for each interview lasting approximately an hour. The goal of the discussion was to understand what skills and capabilities will be required of future engineering and technical workers in the United States. Field notes were made which were then cross analyzed and discussed by the research team. Interview notes were coded and analyzed using Steele's [13] framework of organization typologies and competitive factors. In total, twelve interviews were conducted with four representing system organizations, four representing component/service organizations and four representing natural resource based organizations respectively. The following key questions were posed to participant high ranking technology officers:

- *Due to effects of globalization, which functions are likely to be outsourced and which will remain in US?*
- *Based on what will stay in the US, what skills will be needed from your technical staff?*
- *What is the role of lead technical people?*
- *How do you compete as a company?*
- *What, if any, are the systemic advantages of the US?*

4. Results

The interview responses were analyzed using the framework of organizational typologies. The results have been organized by 1) what functions will remain, 2) what functions will be outsourced and 3) what skill sets will be needed, as identified by high ranking technology executives. Interview notes were analyzed and skill set themes emerged. By contrasting their typology to the above questions the following resulted:

4.1 Natural Resource Based Organizations

In general, the risk of outsourcing engineering jobs is relatively low for natural resource based companies. This is because the natural resource bases greatly drive the location and behavior of the firms. That is, they tend to initiate the project wherever the natural resources exist. These organizations are also concerned with building centers of knowledge where they contain the skills required to find new resources and extract and convert them efficiently. Again, the movement of these centers of knowledge is difficult and not readily affected by globalization trends. Finally, many of these organizations have large distribution systems and channels to get product through refineries to the hands of customers. These distribution systems can not easily be moved or altered. Respondents indicated neither of these operating models is likely to change due to globalization.

Functions which are likely to be performed outside of the United States included non-core competence engineering areas including the creation, operations, and maintenance of accounting and finance software systems. It is interesting to note that Financial Services companies view finance and accounting to be core to their businesses and would not target these functions for outsourcing. However, in resource based organizations we find that financial or accounting systems are not core to competitive methods and are therefore more appropriate for outsourcing.

There is also a measurable trend of overall reductions of vertical scope in this industry. In the past, for example, oil companies used to build the tools and systems used for drilling as well as operate the equipment and recover the targeted oil. More recently, these companies have started to focus on only the exploration and extraction component, while leaving the building of tools and infrastructure to other companies – which may be located anywhere in the world. This trend results in greater dependence on their supply chain of both products and systems often located outside US. The following table illustrates the response of natural resource based company executives when asked about the importance of needed skill sets:

Table 1

<i>Required Skill Categories for Resource Based Organizations</i>	
<i>Rank</i>	<i>Skill Category</i>
1	Fundamental engineering theory is a basis of selection, broader skills are differentiators
2	Ability to see big picture and be driven to achieve
3	Teamwork – openness to take input from others, ability to communicate and present
4	Engineering economics, ethics
5	Project based experience

Respondents articulated that fundamental engineering theory is the primary basis of selection while broader skills served as differentiators. They also felt that ability to see the big picture, being driven to achieve, and ability to work in teams were of particular importance.

4.2 Component/Service Orientated Organizations

These companies compete by developing innovative products under tight schedules. Often, release schedules for each product generation are fixed in advance. Next generation products go into the design process even before market feedback can be gathered regarding the last product version. Component oriented organizations are not able to outsource their design engineering or even significant portions of it, while they are able to readily outsource those functions which do not directly contribute to the organization’s ability to innovate.

For example, firms such as Microsoft find it difficult to perform round the clock (24 hour per day) development with design teams working collaboratively around the world [5]. The reason is that the tight constraints of time pressure prohibit these sorts of methods. For example, information necessary to resolve a particular component design issue may not be available due to another team member’s vastly differing geography causing missed milestones and project overruns. The breakdown is possible between design teams and testing teams. Design teams seem to only grow organically because of the interactions between skills, technology, processes, and overall organizational knowledge. Testing teams, however, can be outsourced without excessive complication. We also note that while technology development capabilities can not be

easily be transferred overseas, they may be grown independently and later acquired. This is the common method by which global design teams end up being created and eventually integrated, but rarely through outsourcing.

Notably, most of the problems identified due to globalization by executives were cross-disciplinary. These cross disciplinary skills involve the understanding of more than one discipline and the ability to communicate with people with different skill backgrounds. One commonly cited interdisciplinary issue exists between different forms of engineering (electrical, mechanical, computer science, etc). A second interdisciplinary issue exists between technology and business context issues including understanding of market dynamics, financial constraints, supply chain issues, product lifecycle costs, and legal / patent issues. Executives felt that good engineers would need some exposure to these related business and legal issues. For some firms, a third interdisciplinary issue existed between engineering and biological sciences.

Areas likely to be outsourced overseas were anything which did not directly contribute to innovation, including those functions which can be reduced to specification or process. Executives indicated manufacturing would be centralized offshore or localized depending on transportation and supply chain costs. In some cases, public relations issues with local markets affected the decision of where manufacturing would be done. Telephone based customer support repeatedly surfaced as having moved or a candidate for outsourcing. Some of the companies will outsource their localized product work unique to that particular geography as well. Table 2 depicts the ordered response of component/service orientated company executives when asked about the importance of needed skill sets:

Table 2

<i>Required Skill Categories for Component/Service Organizations</i>	
<i>Rank</i>	<i>Skill Category</i>
1	Basic design engineering and coding skills.
2	Holistic product design, often complimented by project based experiences
3	Interdisciplinary skills <ul style="list-style-type: none"> a. Technology + finance, legal, market, supply chain (light) b. EE+ME+CS... (within engineering) c. Between engineering, materials, and biological sciences.
4	Cross-functional/global teamwork, communicate and present

Basic design engineering and / or coding skills are considered fundamental. Component/service orientated organizations also stressed holistic product design, interdisciplinary knowledge, ability to work in cross functional and global teams, the ability to communicate and present. For these firms, there is a clear and increasing pressure to work at the edge of technology or at the higher end of the market. When these company's products' or services' performance surpasses market need, these products are targets for imitators [4].

Executives confirm that in some cases product companies have intentions to evolve into systems companies. However, as a digression, we note Steele's extensive comments regarding the difficulty of such a transition. Component companies often lack the experiences, organizational structure, knowledge of the final customer, and management conventions to create integrated systems. Component/service oriented organizations usually have autonomous market facing units - which makes assembling and pricing of integrated systems most challenging. They also feel strong pressure to use their own products in the system which may not be the most cost effective or best solution. Ironically, flexibility is viewed by systems oriented companies as strength, while component/service companies view this as a weakness. Component companies, in contrast, believe a strong technical position, provides the best protection from competitors available.

4.3 Systems Orientated Organizations

The focus of these companies centers on system design and understanding customer requirements. Executives indicated globalization is changing business models in a way that they begin to integrate services more deeply into their offerings to increase switching costs. For example automobile, airplane, and construction equipment manufacturers will look at using information systems to link their products with maintenance services. These companies also have an increasing dependence on supply chain for advanced components and possibly knowledge. Effective and efficient management of the supply chain, relationships regarding design control and intellectual property were all identified as key factors in their long term success.

When asked about which areas are likely to be outsourced overseas executives indicated they will compete by placing greater leverage of their supply chain. They felt the outsourced design of components will continue as larger portions of the design can be reduced to specification. These companies have a clear tendency to move to higher ends, motivated by higher margins. Table 3 depicts the response of systems orientated company executives when asked about needed skill sets:

Table 3

<i>Required Skill Categories for Systems Orientated Organizations</i>	
<i>Rank</i>	<i>Skill Category</i>
1	Fundamental engineering skills
2	Project based experiences and holistic thinking
3	System design skills – include breaking down complex systems into subcomponents, critical thinking, ability to translate into specification
4	Program management and cross-functional/global teamwork, communication, presentation
5	Interdisciplinary specialized engineering skills (examples given include heat, ruggedness, sensors, electromechanical interfaces, also technology + business)

Needed skills included a strong emphasis on system design skills including breaking down complex systems into subcomponents, critical thinking, and the ability to translate into specifications. Program management also emerged as a needed skill set in order to manage subcontractors, issue resolution and the need to understand the big picture in order to arrive at the intended solution.

Systems oriented companies, in contrast to the others, focus on the complete and refined understanding of the customer's needs. The difference in skill set needs is reflected in their approach to offer *solutions* and not capabilities. In general these companies view technology as something that can be acquired and place importance on understanding the system and breaking it down to components and specifications. These companies give highest priority to assembling a system and having technology components supplied at competitive prices.

5. Conclusions

In general, we expect continued demand for engineering functions which can contribute to holistic, product innovation or to the building of large scale systems. We find that not all technical jobs can be exported on the basis of cost advantage. This is particularly true in cases where the job function is highly integrated with the innovation process or integrated with a large scale system design and/or integrated with local customer communication. However, engineering functions which do not contribute to these main areas are more likely to be eliminated over longer periods of time.

As mentioned earlier, we have already witnessed the exodus in manufacturing, phone based customer support, software testing, and certain types of software coding. A more subtle form of job export occurs in the form of higher reliance on supply chains for products, systems, as well as services. Any subcomponent or service which can be reduced to specification is potentially a target for off-shore sourcing.

Reflecting on Steele's [13] framework and the results gathered a number of themes emerge relative to skill set. Table 4 provides a visual of the identified skill sets and their importance relative to the organizational typology:

Table 4

<i>Importance of Skill Categories by Organizational Typology</i>			
<i>Skill Category</i>	<i>Natural Resource</i>	<i>Component/Service</i>	<i>Systems Orientated</i>
Fundamental engineering theory or design/coding abilities	****	****	****
Integrated projects and holistic thinking	****	****	****
Working in (global) teams, communications, presentation, leadership, softer people skills	****	****	****
Interdisciplinary T+M finance, legal/patents, supply chain issues	*	****	****
Interdisciplinary across engineering or engineering + materials and biological sciences	*	***	**
Breaking down systems, reduction to specification	*	*	****
<i>Legend</i>	<i>* Somewhat important</i>	<i>** Important</i>	
	<i>** Very important</i>	<i>**** Crucial</i>	

All three typologies heavily emphasized fundamental theory as a requirement. Also requested by all three typologies were integrated project based experiences and holistic thinking. All three also strongly emphasized working in global team environments. Softer skills such as the ability to communicate and leadership also consistently surfaced. Further, presentation and leadership skills were identified by all organization typologies.

Component/service oriented and systems oriented companies both placed a strong emphasis on interdisciplinary skills including technology, management and the ability to span areas of finance, legal-necessary for patents, and supply chain areas needed for issue resolution. They also placed emphasis on Interdisciplinary areas across engineering such as electronic, mechanical, materials and biological sciences. Although not particularly highlighted in the table, cross-disciplinary is much more relevant to the long term success of component companies,

while system oriented companies clearly emphasized the breaking down of systems into component through specification.

6. Recommendations

As educators, we are concerned about what new job skills will be required and how best to prepare our future graduates. The results of this study may be used to better understand the organizations' behavior given the current economic state in order to anticipate the needs of the engineering profession. Engineering departments may use this study to provide broad guidelines in order to prepare engineers of the future and position them to best benefit from economic changes.

7. Limitations

Limitations of this study include a limited number of interviews with technology executives:

1. There is also the possibility that human resource managers and high ranking technology executives may not agree on skill set needs. Of course there is also the possibility that executives are ahead of the curve and providing needed skill set information that would eventually become the hiring managers' criteria.
2. Also, due to the nature of data collection via interview, there is a relative effect to the weighting of skill set components.
3. It is recognized that the needs filled by Departments such as Computer Science likely cut across organizational typologies discussed and are more likely to inter-work with multiple disciplines.

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