GLOBALIZATION AND ENGINEERING/SCIENCE EDUCATION: DO THEY CONVERGE?

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ABSTRACT

The widening, intensifying, speeding up, and growing impact of worldwide interconnectedness, better known as globalization is forcing countries and regions develop strategies to enhance their economies to better compete worldwide. Science, technology, engineering and innovation play a fundamental role in the creation of wealth, economic development and in the improvement of the quality of life for all citizens. This paper addresses the need to reform and innovate engineering education and its role of capacity building as key foundations to develop national/regional economic development strategies worldwide.

INTRODUCTION

The term "globalization" has gained considerable attention and force during the last few years. Some view it as a process that is beneficial—a key to world economic development—as well as inevitable and irreversible. Others regard it with hostility; even fear, believing that globalization increases inequality within and between nations, threatens employment and living standards, and thwarts social progress. According to the International Monetary Fund [1], globalization offers extensive opportunities for countries around the world but it is not progressing evenly. Some countries are becoming integrated into the global economy more quickly than others. However, in some of those countries that are becoming integrated, the divergence between the richest and the poorest in the country is widening, leaving the poorest even worse off. Still, there is general agreement that globalization is rapidly changing economic systems around the world.

What is globalization exactly and how is it related to engineering and engineering education? Globalization is often defined as the process in which geographic distance becomes a diminishing factor in establishing and maintaining cross-border economic, political, and socio-cultural relations. Thus globalization can be thought of as widening, intensifying, and increasing the impact of worldwide interconnectedness.

KNOWLEDGE-BASED ECONOMIES ARE KEY TO DEVELOPMENT

In a quest to address globalization and its economic challenges, the European Union (EU) set an ambitious target for itself during its March 2000 Lisbon Summit: that Europe "would become during the next decade the most competitive and dynamic knowledge-based economy in the world." Non-EU nations that want to be considered for inclusion in the EU realize that they need to develop their knowledge-based economies. Thus, the World Bank recommends that these nations concentrate all their efforts on four major areas [2]: education and training, information infrastructures, economic incentive and institutional regime, and innovation systems. The basic premise is that knowledge is becoming a primary factor of production, in addition to capital, labor and land. In fact, many economists now argue that knowledge has become the most important component of production. The belief is that a knowledge economy will lead to improved quality, reduced costs, better response to consumer needs, and innovative products. However, there is an increasing digital, scientific and technological divide between developed countries that are exploiting knowledge, science and technology for economic well being--and those less-developed countries (and less-developed regions within countries) that are not fully participating in globalization.

In the *World is Flat*, author Tom Friedman [3] suggests the world is in its third wave of globalization, one that is governed by people and communications. He states that the flattening of the world happened at the dawn of the 21st century; and that countries, communities, individuals, governments and societies can and must adapt to the challenges that this "flat world" presents. Thus, globalization is making both developed and developing countries think about effective and efficient strategies that will advance their economies and social development. Many countries around the world have made significant strides in the past 10 years in laying the foundations upon which market economies and democratic societies can flourish. Examples include Taiwan, Singapore and Ireland.

The World Bank recommends that countries that want to develop their knowledge-based economies focus on four areas:

- **Education and training--**an educated and skilled population
- **Information infrastructure--**a dynamic information infrastructure--ranging from radio to the Internet.
- **Economic incentive and institutional regime--**a regulatory and economic environment that enables the free flow of knowledge, supports investment in Information and Communications Technology (ICT) and encourages entrepreneurship.
- **Innovation systems--**a network of research centers, universities, think tanks, private enterprises and community groups that can tap into the growing stock of global knowledge, assimilate and adapt it to local needs, and create new knowledge.

To "use knowledge for development" as the World Bank recommends, a country must ensure its people have the right set of knowledge, skills, competencies and values. It is people in the NGO, government, academic and private sector who develop the necessary information infrastructure, the economic incentives and institutional regimes, and the innovation systems. The United States has long set the world benchmark for building a knowledge economy, but the World Bank points to additional nations that have addressed these four points systemically and efficiently. Finland, Ireland and Korea are clear examples, where significant reform and investments have been made in science and technical education, and innovation systems.

ENGINEERS ARE KEY TO DEVELOPING AND GROWING KNOWLEDGE-BASED ECONOMIES

If technology and knowledge form the basis for meaningful economic development, given that globalization is radically accelerating the pace of change and raising the long-term stakes, it is clear that success in knowledge-based economies depends largely on the capabilities of people who are credentialed in meaningful and consistent ways. Further, the kind of knowledge countries need to develop is key: first, literacy of the general population, and then educating problem-solvers who can build the technical infrastructure for sustainable change. *Engineers are the ideal problem solvers.* When you consider that economic studies conducted before the information-technology revolution show that as much as 85 percent of measured growth in U.S. income per capita was due to technological change [4], a strong case can be made for seeing engineers as the key knowledge workers for capacity building and sustainable economic growth in emerging economies.

It follows, then, that to effectively compete in the knowledge-based economy, developing countries must invest in producing a large enough pool of high-quality and accredited engineering graduates. Of course, the pool will be drained somewhat because some of these graduates will leave for jobs in developed countries. However, many will choose to stay where family ties and native culture provide a comfortable environment and competitive quality of life. By building the technical capacity of their workforce, through quality engineering-education programs, countries can build a competent technical workforce, which can provide several paths to economic development: attraction of technically oriented multi-national companies that can invest in the country; effective use of foreign aid funds to build appropriate infrastructure projects, and then have the technically competent citizens of the country to operate and maintain them; and creation of small business startups by technically competent entrepreneurs who either live in the country, are living elsewhere but return home, or immigrate from other countries. Both the United Nations Educational, Scientific and Cultural Organization and the World Federation of Engineering Organizations are actively engaged in technical capacity building in developing countries [5].

THE IMPERATIVE TO INNOVATE AND REFORM ENGINEERING EDUCATION

High-quality and pertinent engineering education, and quality-assurance mechanisms are imperatives for creating a knowledge-based economy. Engineering education must respond to local challenges as well as global opportunities. Quality-assurance systems with peer-review accreditation must be present to promote high-quality education programs and make degrees portable to other parts of the region and of the world. Quality-assurance systems can provide the basis for cross-border recognition systems, permitting the flow of services and goods across national boundaries and creating a net ‘brain gain’ for the country or region.

To innovate and reform engineering education, a country’s educators need to understand what an engineer is, and what skills and competencies s/he must possess. Their education and professional development is not only about knowledge, but also about skills, values and competencies. Engineers face problems as a way of life. Engineers must not only be knowledgeable about science and technology but also have the skills, competencies and values to address problems and opportunities in effective and creative ways.

Higher education, in general, is responsible for formally preparing the next generation of business leaders, technical professionals, government officials and educators. Engineering education, in particular, plays a central role in our increasingly technology-based societies. The education of engineers must prepare them for the multi-disciplinary nature of the problems they will face.

But is engineering education preparing the kind of professional that's needed to solve local problems and face global opportunities?

The need to innovate and reform engineering education is vital and undeniable. In the United States, for example, prestigious organizations like the National Science Foundation (NSF), the American Society for Engineering Education (ASEE), the National Academy of Engineering (NAE) have reported on the growing need for change in engineering education [6,7,8]. Sweeping changes in accreditation criteria made in 2000 by the Accreditation Board of Engineering and Technology (ABET) are evidence of the context for engineering accompanied by significant changes in the challenges offered by the engineering workplace bringing urgency to the need for broad change in the education of engineers.

But herein lays the problem: Engineering education has not traditionally concerned itself with the development of skills and competencies needed in the job market and workplace. According to Richard M. Felder, co-director of the U.S. National Effective Teaching Institute, "We're teaching the wrong stuff [9]." He argues that since the 1960s, the United States has concentrated almost exclusively on equipping students with analytical (left-brain) problem-solving skills, and that a) most jobs calling for those skills can now be done better and or cheaper by either computers or skilled foreign workers (and if they can be, they will be), and b) American workers with certain right-brain skills will continue to find jobs in the new economy. (For example, researchers, designers, entrepreneurs as well as other self-directed people, and people with strong interpersonal, cultural awareness and language skills.) Felder questions whether the U.S. education system is helping students develop the attributes they will need to be employable in the coming American and global engineering job market.

To better understand the programmatic implications of the broad changes needed in engineering education, in 1995 the NSF organized a workshop on restructuring engineering education [8]. The task was to address the curricular content (including experiential, contextual and service-learning activities) and the broad academic framework of an engineering education. Workshop attendees included individual investigators, engineering education coalitions, engineering societies, industry and students. They concluded that, to be restructured, engineering education must be examined from a different point of view, with new measures and expectations.

In their report, workshop participants called for diversity in all aspects of engineering education: diversity in pedagogy, curriculum, cross-disciplinary approach, faculty and students. Restructuring requires rewards and incentives designed to achieve the desired diversity.

Workshop discussions and recommendations focused on four dimensions deemed critical to engineering education reform:

- **Students are central to the educational process**. As such, they should be active participants in the educational transformation process. The educational experience should develop in students the motivation, capability, and knowledge base for lifelong learning.
- **Faculty** need to assume a more active role not only in delivering the educational experience but also in innovating and continuously improving engineering education to meet the new global challenges. Changes in assessment, recruiting and the reward structure are most critical for encouraging faculty changes.

- **The learning experience** must move away from lectures as the dominant mode and toward a higher level of active learning approaches, such as laboratory and internship experiences. These experiences should encourage world-class design, development and implementation processes for engineering. Cooperative learning approaches and other contextual and experiential learning must be integrated into the classroom.
- **Engineering curricula** should be broad and flexible, preparing students for leadership and specialist roles in a variety of career areas. Each curriculum should be designed to produce graduates who are life-long learners and contributors to the profession, fully capable of succeeding in a global, multi-disciplinary marketplace. The learning experiences should accommodate students with various learning styles as well as different cultural, ethnic, class, gender, age and racial backgrounds. Further, engineering education should provide an opportunity for non-majors to study engineering topics and concepts, and enable engineering discipline and approaches to inform other disciplines.

HOW TO PREPARE THE NEXT GENERATION OF ENGINEERING STUDENTS – THE U.S. NATIONAL ACADEMY OF ENGINEERS REPORT

In 2005, the National Academy of Engineering published its report, *The Engineer of 2020: Visions of Engineering in the New Century* [8]. The report begins with the premise that for the United States to maintain its economic competitiveness and improve the quality of life for people around the world, engineering educators and curriculum developers must anticipate dramatic changes in engineering practice and adapt their programs accordingly. Written by a group of distinguished educators and practicing engineers from diverse backgrounds, the report includes various future scenarios based on scientific and technological trends. In addition to identifying the ideal attributes of the engineer of 2020, the report asks: "What should engineering education be like today, or in the near future, to prepare the next generation of students for effective engagement in the engineering profession in 2020?" The report recommends ways to improve training to prepare engineers for addressing the complex technical, social, and ethical questions raised by emerging technologies.

WHAT IS THE ROLE OF THE PROFESSOR?

Traditional scholarly work (including engineering) centers on the professor, his/her course(s), and his/her professional career and research agenda. Teaching is often considered secondary, even a burden. Faculty is mostly rewarded for research activity and outcomes.

But the need and changes described in the NSF and NAE reports shared above will be an insurmountable challenge if education does not recognize and value the scholarship of teaching, in addition to the scholarship of discovery [9]. We need to ensure that the full range of scholarly activity by college and university faculty is recognized: discovery, integration of knowledge, teaching and service. We need to create a reward system that values faculty's full range of scholarly activity**,** one that recognizes those who make an effort to bridge the 'disconnects' that exist between academia and the real world [10], especially in the teaching of engineering. Because as Richard M. Felder states "…College teaching may be the only skilled profession for which no preparation or training is provided or required" (http://www.ncsu.edu/felder-public/) [11].

If the key to economic development is people, the question arises, "What can one person do?" For one, a professor can use his/her engineering skills and address the problem!

Listen to stakeholders, use non-conventional teaching and learning strategies in the classroom, including active and cooperative learning, hands-on learning and a focus on problem-solving skills instead of the usual tons of theory. Some examples follow.

USING COOPERATIVE LEARNING IN THE CLASSROOM

Departing from the traditional teaching method and instead using a cooperative approach that included think-tank/in-class problem-solving, joint quizzes, one-minute papers and study group can bring extraordinary results with relatively little effort. After trying the technique in in one Chemical Engineering course that had an historical attrition rate of 50 percent to 60 percent, Morell and Velazquez [12] tried to prove the value of the cooperative learning strategy. As seen in Figure 1, overall, 77.4 percent of the students participating in the cooperative learning experiment passed the course with a grade of C or better, compared to 28.6 percent of students in the control group.

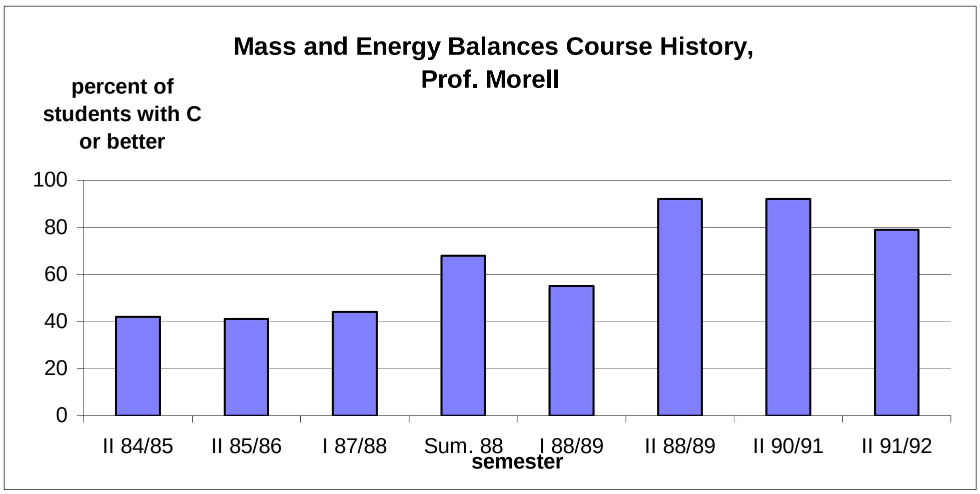

Figure 1 Cooperative Learning results

THE LEARNING FACTORY: A MULTI-DISCIPLINARY, ACTIVE-LEARNING PROGRAM

In 1994, a university-industry partnership called the Manufacturing Engineering Education Partnership (MEEP) aimed to integrate design, manufacturing and business realities into the engineering curriculum. The MEEP team developed the Learning Factory, a multi-disciplinary program that provides real (industry-driven) projects; a curriculum in product realization; and a state-of-the-art, hands-on learning laboratory, with strong industry participation and integrated outcomes assessment. The Learning Factory began as the result of a joint National Science Foundation/Defense Advanced Research Projects Agency grant, and was undertaken by Sandia National Labs and three universities: University of Puerto Rico at Mayagüez (UPRM), Penn State University and the University of Washington. This program, which integrates an outcomes, competency-based curriculum with assessment and industry partnership, continues to grow over a decade since it began [13, 14, 15, 16].

The fundamental innovations of the Learning Factory that made the greatest impact at the universities were:

- **Facilities:** The Learning Factory is an open-access, active-learning laboratory, where students, faculty and industry from all disciplines can practice real engineering. It provides practical training and modern facilities for design, prototyping, manufacturing, testing and re-design. These facilities support numerous student design projects and competitions, enabling faculty to integrate engineering practice into their courses.
- **Industry interaction:** The Learning Factory provides an efficient infrastructure for actively involving industry in the educational process through capstone design projects, curriculum improvement and engineers in the classroom.
- **Curriculum:** The product realization minor, or manufacturing certificate, is comprised of elective courses in product dissection, concurrent engineering and engineering entrepreneurship; and required courses in manufacturing processes, quality control and capstone design.

In 2006, Jens E. Jorgensen (University of Washington), John S. Lamancusa (Penn State University), Allen L. Soyster (Northeastern University), José Zayas-Castro (University of South Florida) and the author received the National Academy of Engineering’s Bernard M. Gordon Prize -- a $500,000 annual award that recognizes innovation in engineering and technology education, “For creating the Learning Factory, where multidisciplinary student teams develop engineering leadership skills by working with industry to solve real-world problems."

Figure 2 MEEP Team win NAE Gordon Prize, February 2006

LEARNING FACTORY EXPERIENCE DRIVES UPRM ENGINEERING ACCREDITATION STRATEGY

UPRM’s College of Engineering ABET 2000 accreditation strategy was based on the Learning Factory experience. The strategy incorporated the outcomes assessment plan and tools developed under MEEP and PaSCoR. In order to institutionalize the assessment process as part of the various courses, the College of Engineering established an office called the System for the Evaluation of Education (SEED), with the goal of developing assessment strategies for the undergraduate engineering programs. In addition, the faculty involved industry and employers in its process, and conducted mock “accreditation visits” where industry members gave input about the programs. The UPRM ABET committee organized a series of one-day workshops that led to the development of a package of assessment tools and strategies. This was adopted for common use by all programs, with each one at liberty to modify or choose from among the recommended methods and tools. The package contains an outcomes assessment matrix; an assessment strategies matrix; and various assessment forms for integrating ethics, oral and written reports, teamwork, peer evaluation, course and project evaluations, internships, and a variety of surveys.

All six of the undergraduate engineering programs were evaluated in 2002. ABET's accreditation visit team commented: "*The institution's systematic and innovative effort to introduce the culture of outcomes-based assessment to the College of Engineering community is especially noteworthy.*" As a result of these experiences, UPRM is expanding the quality assurance and outcomes assessment efforts institution-wide. These efforts and documentation solidify the institution's magnet to attract more than 100 national and multinational companies that recruit graduates, especially engineering.

CONCLUSION

Engineering education and economic development meet this convergence helps achieve economic development. It happens when engineers make a difference, when they possess the skills, competencies and values to make a significant contribution to their countries, regions and ecosystems. Engineering education that focuses on outcomes and on producing engineers that society, regions, nations and the world need is an imperative, one that countries committed to bettering the lives of their citizens must address.

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