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Innovation in research and engineering education: key factors for global competitiveness

Innovación en investigación y educación en ingeniería: factores claves para la competitividad global

TRANSFORMING ENGINEERING EDUCATION IN LATIN AMERICA: A CHALLENGE FOR COMPETITIVENESS IN THE GLOBAL ECONOMY

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Abstract

The globalization effect is causing rapid transformations in social and financial conditions around the world; therefore, it is important to understand all the variables affecting the global economy and identify the strategic model to be competitive and contribute to the growth of the Latin American countries. This new model is calling for technological improvement to enhance the productive capacity and reach new markets. Consequently, it is very important to prepare the human capital capable for not only enabling the technological transformation but also creating new industries for economic development and competitiveness. Changes in the global economy, especially the importance of moving to a knowledge-based economy, have changed the role of engineers and engineering education in this millennium. The new global environments have changed the skills required for engineers. It is imperative to educate engineers with a set of competencies including technical knowledge, professional skills, and personal and social trait to contribute to the competitiveness of the region. Preparing these global engineers requires a shift in paradigm in their formation and this paper explores some transformations in engineering education to better prepare engineers to lead the transformations for global competitiveness.

Keywords: engineering education; competitiveness; human capital; global economy; Latin America

Resumen

El efecto de globalización está causando rápidas transformaciones en las condiciones sociales y financieras alrededor del mundo; por lo tanto, es importante entender todas las variables afectando la economía global e identificar el modelo estratégico para ser competitivos y contribuir al crecimiento de los países Latino Americanos. Este Nuevo modelo está llamando a la mejora tecnológica para aumentar la capacidad de producción y llegar a nuevos mercados. Por consiguiente, es muy importante preparar el capital humano para no solo permitir la transformación tecnológica, sino también la creación de nuevas industrias para el desarrollo económico y la competitividad. Los cambios en la economía mundial, en especial la importancia

de avanzar hacia una economía basada en el conocimiento, han cambiado el papel de los ingenieros y la enseñanza de la ingeniería en este milenio. Los nuevos entornos globales han cambiado las habilidades necesarias para los ingenieros. Es imprescindible educar a ingenieros con una serie de competencias como conocimientos técnicos, habilidades profesionales, y el rasgo personal y social para contribuir a la competitividad de la región. La preparación de estos ingenieros globales requiere un cambio de paradigma en su formación y este trabajo explora algunas transformaciones en la educación en ingeniería para preparar mejor a los ingenieros para dirigir las transformaciones para la competitividad global.

***Palabras clave**: educación de ingeniería; competitividad; capital humano; economía mundial; Latinoamérica*

1. Introduction

The establishment of new regional economic alliances beyond the frontiers of a single nation has required that engineers be prepared to work in an economy that is now best seen as essentially international in nature. Almost all major corporations now operate globally, and engineers are being challenged to design and develop, in a timely manner, new products that will impact a global market (Esparragoza and Devon, 2005). Due to this tendency, future engineers will be facing the new worldwide market where the barriers of the corporate world are disappearing. The global engineer must understand and accept diversity, be able to work in multi-national corporations, be able to work in multi-cultural teams, be able to propose solutions to problems impacting a wider and more diverse population, be able to communicate and socialize with people from different cultures, be able to use the technology to exchange ideas, solve problems and present solutions (Esparragoza, 2005). On the other hand, there is an increasing perception of the need for graduates of engineering to be creative thinkers and innovators from industry and professional associates. Additionally, it is evident that technology is a predominant force in transforming underdeveloped regions into prosperous and high tech areas (Lécuyer, 2001). The transformation of Silicon Valley can be cited as an example, as well as the technological revolution experienced by many Asian countries such as Singapore, China, Taiwan, Korea and Japan where the investment and development in technology has transformed the economy and lifestyle of those countries. Finally, in recent years, fostering entrepreneurship has become a topic of the highest priority in public policy throughout most industrial countries. This trend can be attributed to the growing awareness that new firms are a driving force of economic growth and job creation (Franke and Luthje, 2003). As a result, the engineering entrepreneurship has become popular in many academic institutions due to the necessity of training the student to combine the technical knowledge with the business background for product conceptualization, innovation and design, technical feasibility analysis, and market research and analysis (Sathianathan, 2002).

New financial models, where free trade agreements are being established in different regions, demand the formation of engineers with solid technical formation capable of working in cross-disciplinary and multinational teams. The new engineers for the Americas should be aware of the global nature of their profession, be versatile, creative and effective leaders to make the individual nations competitive and the new economic blocks sustainable and strong. This has been recognized in many developed countries and a great effort is being made to provide that formation for the new generation of engineers. Technology development is obtained mainly by investing in education and research to recruit and prepare the future engineers for discovering and implementing new advances in science and engineering. However, it has been observed that while universities in developed countries are teaching global design, engineering entrepreneurship, and forming alliances and consortiums to establish international collaborations, most of the educational institutions in Latin America and the Caribbean are behind in this type of initiative, with

practically no engineering design and entrepreneurship courses, and few international projects. There is still a great effort in forming engineers for service but not for developing new products, systems, and/or businesses. This lack of formation of Latin American and Caribbean engineers makes difficult to generate a technology revolution in these countries, placing the whole region at a disadvantage compared to other regions.

The role of the educational institutions is to satisfy the needs of the communities and in particular of the productive sector in terms of human development and collaborative work. Mauricio Ramos (2000) in his article *Reflexiones sobre la vinculacion de la actividad cientifica y tecnologica con el sector productivo* calls for an alliance between the productive sector and the scientific and technological activities developed in universities and other research centers to enhance the competitiveness in global economies through research and service. This paper is related to the development of the human capital necessary to create the transformations and contribute to the enhancement of all the sectors that contribute to the economic growth.

2. Challenges for Latin America

It is evident that the process of globalization, a process that is transforming the social condition of the humankind, brings extraordinary challenges, especially for developing countries. The foreign competency is probably the biggest challenge. The Latin American and Caribbean countries do not have yet the technological infrastructure, a robust economy, and the human capital to compete with the developed countries. Besides that, the research and development (R&D) culture is not strong putting the whole region behind in terms of scientific and/or technological development. However, the globalization phenomenon also brings opportunities. The markets become bigger and more diverse; there is more and easiest access to new technology; and the transfer of knowledge increases. All those elements contribute to enhance the living standards in underdeveloped regions.

The only way to take full advantage of the opportunities offered by globalization is to understand the challenges faced by the region and take actions to face them properly. One of the key elements to be competitive in the global market is to invest and enhance in engineering education. This will provide professionals capable of incrementing productivity through creativity, innovation and design. As a result, there will be an enhancement in infrastructure and technology. This trend will provide opportunities for the development of mid and small enterprises as part of the productive force. It is important to create a close circle by re-investing in engineering education to create a cycle of total quality improvement: improving education to improve productivity to develop new technologies to create new business.

The competitiveness indices presented by the World Economic Forum and that can be found in http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2012-13.pdf clearly show the need of change in education particularly in higher education training, and technology readiness, and innovation. An analysis of the data reflects that only five out of 24 countries from Latin America and the Caribbean are in the top 50 in competitiveness for higher education, seven for technology readiness, and only four for innovation. A more detail analysis of those indicators are summarized in Table 1. It is observed that the competitiveness indices reflect a poor performance for the region in all the areas with only few exceptions such as the high score of Barbados in internet users, of Brazil and Guyana in secondary education enrollment, and of Puerto Rico in the availability of engineers and scientists.

These indicators clearly show that there are some serious challenges ahead for the Latin American and Caribbean nations to be competitive. It is clear that there is a lack of human and infrastructure resources for innovation and business development. There should be a strong compromise from all the stakeholders to make the necessary changes at all levels to face those challenges. These changes are calling for a synergy among the private sector, the government, and educational institutions to prepare the human capital, invest in infrastructure, research and development (R&D), and facilitate the establishment of new businesses for economic growth.

Table 1. Global Competitiveness Index for Latin American and Caribbean Countries 2012-2013: Some indicators in Education, Technology Readiness and Innovation

	Education		**Technological readiness**		**Innovation**		
Country	**Secondary enrollment**	**Tertiary enrollment**	**Internet users**	**Availability of latest technology**	**Capacity for innovation**	**Company spending on R&D**	**Availability of scientists and engineers**
Argentina (ARG)	73	20	60	109	95	91	80
Barbados (BAR)	30	24	31	28	91	72	54
Bolivia (BOL)	91	64	89	134	61	71	108
Brazil (BRA)	17	80	62	50	34	33	113
Chile (CHI)	75	38	50	32	83	61	29
Colombia (COL)	46	63	70	91	66	69	94
Costa Rica (COR)	34	81	68	57	43	41	27
Dominican Republic (DOR)	96	72	79	60	118	99	125
Ecuador (ECU)	98	62	87	102	82	73	96
El Salvador (ELS)	105	84	101	88	107	106	139
Guatemala (GUA)	109	97	115	51	67	66	88
Guyana (GUY)	61	105	83	70	35	46	103
Honduras (HON)	100	92	104	78	98	80	119
Jamaica (JAM)	55	75	86	44	85	107	101
Mexico (MEX)	71	78	77	52	75	59	71
Nicaragua (NIC)	102	94	118	133	87	102	130
Panama (PAN)	99	57	66	30	94	34	99
Paraguay (PAR)	104	70	93	100	109	110	134
Peru (PER)	59	58	76	75	103	118	120
Puerto Rico (PUR)	87	6	59	31	38	35	3
Suriname (SUR)	97	104	83	110	106	115	111
Trinidad and Tobago (TRI)	66	106	49	63	124	100	56
Uruguay (URU)	65	25	53	82	74	57	117
Venezuela (VEN)	86	11	71	103	134	127	126

3. Economic Transformations

Countries competing at the first level of basic requirements are basically satisfying local needs and their economy is based on unskilled labor and natural resources. As countries advance in the competitiveness scale, then a more educated human capital is needed to improve efficiency and quality in processes and products. At the efficiency-driven level, countries not only satisfy basic needs but also start developing some technology and reaching new markets. To reach the final level of competitiveness, innovative-driven, the production of processes and products reach a level of sophistication to become a leader and innovator demanding a much better prepared human capital (Vares, et.al., 2011).

It is then evident that technology transforms the economy and plays a significant role in global competitiveness becoming a predominant force in the transformation of underdeveloped regions into prosperous centers of high development. Silicon Valley can be cited as an example of such a transformation. This region changed from an agricultural district in the 1920's into a high tech complex in the 1990's employing more than half a million engineers by year 2000. Similar transformations have occurred in Asia where the investments in research and development have transformed the economy and the living style of those countries.

Significant investments in science and technology during the 1990's in some Asian countries are paying back notable economic dividends in areas on high technology. This can be reflected in the growth of China and other Asian countries. Most of technological companies are looking toward the Asian markets due to the rate of economic growth of those countries. A quick look at the rate of growth of the gross domestic product (GDP) shows that the first two countries are China and India. Some countries in Asia have found they niche for economic growth. For example, India has become a leader in Information Technology (IT) and there are more than 500,000 IT professionals in India working on this field.

4. Transforming Engineering Education

The basic strategy for economic development is based on three pillars: new technology, leadership, and entrepreneurship supported by efficient governmental policies and stable financial markets. Therefore, engineers, technology and innovation are fundamentals elements for the sustainable growth of not only developed but also emergent economies. The changes in innovation and technology are the main long-term driving forces of the productive growth and the competitiveness in advanced economies. Additionally, high rates of entrepreneurship have a positive impact on innovation, productivity and competitiveness because new firms typically use a more efficient mix of labor, capital and technology than existing firms (National Competitiveness Council, 2005).

It is evident that the great force behind economic transformations and sustainable growth is the technological development; but it is not only about investment in research and development but also about the development of the human capital capable of carrying out those transformations for the economic growth and competitiveness of the region. In that sense, engineers play a fundamental role in the economic growth of the regions. They not only solve local and global problems but also create and transfer knowledge. Thus, it is imperative that in educating the engineer for the new millennium, the technical know-how should be supplemented with professional skills such as creativity, business, teamwork and ethics among others. This requires changes in the educational model, investment in education, research centers, and infrastructure.

Figure 1 shows that the advance in the competitiveness scale will be possible by developing the human capital with the high technical and professional skills necessaries to reach the level of innovation-driven economies.

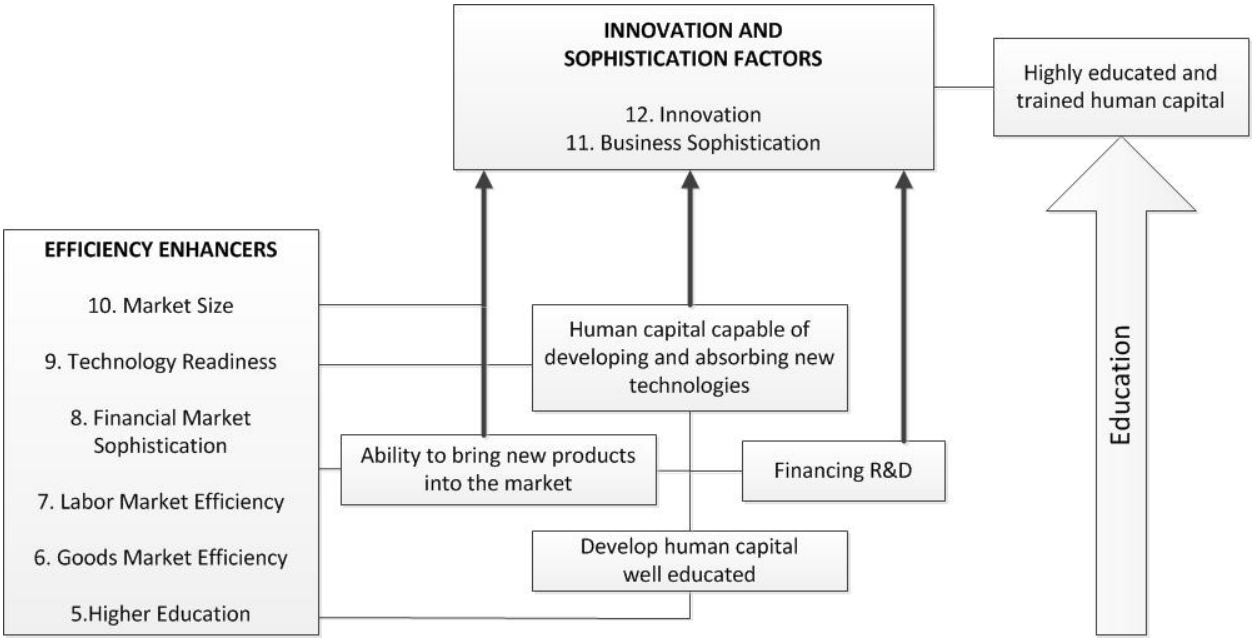

Figure 1 Diagram of transition from efficiency-driven to innovation-driven economies

The proposed model calls for transformations in four main domains: conceptual, content, competencies and approaches. The first one, called the conceptual domain, is related to a change in mentality and the way engineering is seen in Latin America (LA). This domain requires changing fundamentally the professional profile of engineers in LA. In general, the current engineer education in LA is focused in preparing an engineer for service, operation and testing while the global competitiveness is calling for engineers prepared for design, development, research and entrepreneurship. The second change will take place in the content dimension. Engineering curricula are intimately related to the professional profile of engineers. If the conceptual dimension calls for a new profile of engineers, then this dimension requires to change the content by incorporating engineering design, innovation, leadership, and entrepreneurship longitudinal and transversally across the engineering curricula. The third dimension calls for adoption of global competencies in engineering for competitiveness. Here, core, discipline and professional competencies should be properly balanced to provide the skills, knowledge and attitudes that engineers need for global competitiveness. The last dimension calls for a change in the pedagogical approach. Changes in this dimension should ensure that engineers are better prepared to face the global challenges and are competitive. This requires a shift from an instructor-centered approach to a student-centered approach based on active-learning and inquiry-based learning. This dimension has the goal of making the learning process not only more effective in preparing the human capital needed for competitiveness but also more appealing to the students.

Table 2 summarizes the four critical domains to be considered to transform engineering education in Latin America and the Caribbean.

Table 2. Educational Transformation Based on Four Dimensions

Conceptual: change the form engineering is conceived in LA. *Main characteristics*: envision future LA engineers as: • designers, • developers, • entrepreneurs, • researchers.	***Content:*** change the curriculum to balance basic and discipline engineering science with creativity, research and leadership *Main characteristics*: incorporate in the engineering curricula (longitudinally and transversally): • engineering design, • innovation, • leadership and • entrepreneurship
Competencies: change expected outcomes to balance core, discipline and professional competencies. *Main characteristics*: ensure that engineers are educated with the skills required for global competiveness including: • problem-solving, • critical-thinking, • computational-thinking, • creative thinking, • entrepreneurial skills, • communication skills, • teamwork and leadership skills, • ethical skills and • global awareness skills.	**Approaches:** change the traditional classroom lecture, instructor-centered and passive-learning approach into a more dynamic learning environment. *Main characteristics*: adopt innovative and students-centered pedagogical approaches based on: • active-learning, • project-based-learning and • inquiry-based learning approach.

The four dimensions discussed above provide a framework for an educational transformation of engineering education in LA. More specific actions depend on the local necessities and realities of individual countries and institutions. Generally speaking, the way engineering is conceived in LA requires a joint effort of academia, industry and government. The competitiveness plan of each country should identify priority areas and the industry should adopt new models to enhance the production model and technological development. At that moment, the academia should adjust their engineering programs to prepare engineers for the new challenges. The curricula should not only incorporate creativity, research and leadership but also should ensure that programs are more focused on development and more specific in their scope. This requires also to strength technology programs in LA to educate the productive human capital. Engineers should be trained with emphasis in design, development, mathematical complex analysis, simulations and research while technicians should be trained for testing, production, manufacturing, operation, service, maintenance and distribution. These two changes related to conceptual and content dimensions might be the most challenging ones and will take time to implement but they are necessaries for competitiveness. However, a good starting point in transforming engineering education in LA immediately would be to start adopting engineering curricula based on competencies taking into account the new skills for global competitiveness. This can be supported by adopting new instructional approaches where students are more engaged in their learning and develop hands-on experience, and where research, design and product/systems development become fundamental practices. The next step of this work is to analyze some engineering program in LA and provide some specific recommendations under the framework presented on this work.

5. Conclusions

This work present an overall overview of the challenges faced by LA countries based on the global competitiveness indexes by the World Economic Forum. The data clearly shows that it is imperative to advance in many fronts; however, this paper focuses on those related to education and technology which are crucial to transition to higher level stage of development until reaching the innovation-driven economy level. It is evident that the twelve pillars of competitiveness are not independent and it is extremely important to develop a synergy between the government, academia and private industries for the countries to be

globally competitive. For example, the change of concept about engineering as proposed in this paper requires private industries to start investing more in research and development and to require from the universities engineers with that profile that can get into those job opportunities. Without that change of mentality in the industry changes will not be possible at the university level.

The Latin America and Caribbean region has the challenge to enhance secondary and higher education by expanding coverage (increase quantity), improving quality, strengthening STEM areas and incorporating professional skills in technical careers not only to attract and retain more students in the engineering and technology fields but also to prepare world-class engineers for global competitiveness. If technology is a key element for economic growth and design and innovation is a key element for technology development, then it is needed to educate engineers who enable the development of new technology by: promoting engineering design through the curriculum, fostering innovation, creativity, leadership and entrepreneurship, and facilitating the development of competencies and skills for the solution of local and global problems. Future engineers should be also educated with high ethical standards. They should be aware of his responsibility with the society and the environment, and their role in the technological changes and economic growth of the region.

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Los puntos de vista expresados en este artículo no reflejan necesariamente la opinión de la Asociación Colombiana de Facultades de Ingeniería y de la International Federation of Engineering Education Societies