ENGINEERING EDUCATION, THE FAST TECHNOLOGICAL REVOLUTION AND THE INNOVATION LOOPS

Luiz Carlos Scavarda do Carmo[1], Therezinha Costa[2] and Marcos Azevedo da Silveira[3]

ABSTRACT *– The Industrial Revolution History presents knowledge as part of the industrial economy. Science and Education, nevertheless, changed from distant partners to central players of innovation. Engineers thrive in the interface between sciences, technology, market evaluation, and customer habit comprehension and business organization. The present dynamic changes drive a continuous readjustment of professionals. Engineering Education must respond to these changes by forming flexible professionals. This article analyses the consequences for engineering education of the fast growth of new technologies; especially Nano-engineering, information technology and the new thrust on bio related engineering. The connection between basic and applied research and production is analyzed in its short loop where entrepreneurs create technologically based enterprises, thirst in knowledge but not capital. The long loop of innovation fuels large enterprises dependent on knowledge and capital. This article discusses the consequences of the knowledge dependence of these loops of innovation on Engineering Education and on research practices on undergraduate and graduate studies.*

Index Terms – Engineering Education, Entrepreneurship, Innovation, and Productive Sector.

INTRODUCTION

The process of innovation comprises the practice of research, where either new phenomena are discovered as new applications of the known phenomena are found. Moreover, the process of innovation comprises also the practice of education where minds are formed.

The fast growth of technological changes, that characterizes the present moment of history, not only creates an immense pressure on the industrial sector (manufacturing or services) for more productivity, but also transforms the existence of an educated population in an important National asset. This fact has overcome even the importance of raw material availability, considered as an essential strategic item a few decades ago.

The technical literacy became part of this National asset, and education in sciences and technology has become a relevant tool for development.

Engineering Education, if forging properly competent professionals, became a very important social tool for national and social development. This subject, nevertheless, should be understood within a general scope of development of the scientific and technological aspects of the K-12 (elementary and High School) Education

The motivation underlying all the mechanisms in use on the educational process of the engineers respond to the necessities of the social and technological environment under the influence of the School of Engineering. Engineering Education is, at the same time, a product of the local environment and an important tool for local development. Reform programs on Engineering Education should analyze carefully not only all the important technological aspects in use on the productive sector (manufacturing and services) as well as the technologies in development that will, certainly, be available for use in the future.

One clear example in the United States is the several programs undertaken by the National Science Foundation that always started with a careful analysis of the state of the industry and always took into consideration the opinion of the productive sector [1].

HISTORICAL BACKGROUND

One of the main tasks of the engineer has been his or her ability to transform knowledge into products. Along the History of the last 200 years or so, Innovation always represented one of the most powerful mechanisms of changing the production of wealth.

The Industrial Revolution has been a historical changing which may be always marked by technological developments.

The aspects of the Industrial Revolution were marked by several waves that characterized distinct moments of the industrial revolution. These waves may be defined by the characteristics of the innovation process in each period.

Historians distinguish three distinct waves along the Industrial Revolution [2]. The first wave was the revolution start up itself, then, two other successive waves followed.

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[1] Luiz Carlos Scavarda do Carmo, Pontifical Catholic University of Rio de Janeiro, Vice Presidency of Development and Department of Physics, R. Marquês de São Vicente 225, Rio de Janeiro, RJ 22453-970; Brazil - scavarda@vrd.puc-rio.br

[2] Therezinha Costa, Pontifical Catholic University of Rio de Janeiro, Department of Computer Sciences, R. Marquês de São Vicente 225, Rio de Janeiro RJ, 22453-970, Brazil - tcosta@inf.puc-rio.br

[3] Marcos Azevedo da Silveira, Pontifical Catholic University of Rio de Janeiro, Department of Electrical Engineering, R. Marques de São Vicente 225, Rio de Janeiro, RJ 22453-970; Brazil - marcos@ele.puc-rio.br

These waves represent continuous processes of decentralization [3].

The Industrial Revolution, initiated in England in the XVIII Century, changed definitely modern societies from agrarian and handcrafted to industrial with machine manufactures. The social changes are profound, and this may be realized by the fact that this period saw the birth of factories. The agriculture became an industrial work. An important fact was the use of empiricism to create knowledge that means that Engineers could innovate, at this time, using only the available empirical knowledge created by the handicraftsmen. In other words, in the very beginning of the revolution the new social tissue tried to avoid changes due to the industrial process by keeping in the factories the culture brought by the craftsman.

People moving from the countryside swelled Cities, and no major educational changes were performed in the beginning. The culture of the countryman suffices to keep the new engines running.

The first wave of the industrial revolution is an important example of the profound social modifications that new productive process may start.

The hallmarks of the first industrial revolution were:

- The initiation of the factories as a center of the production process and the starting of the working class
- The transformation of agriculture into an industrial toil
- The starting of the machine manufacturing
- The increase of the size of central cities

The first wave of the industrial revolution changed profoundly the society of the Central countries, at that time almost only England. The other countries suffered from the dramatic change of competitiveness of the industrial products that became better and cheaper. Since innovation was still mostly based on empiricism, this period saw no need for educational reforms.

One hundred years after the first wave of the industrial revolution, several inventions changed the landscape of the industrial processes. Those inventions were basically the internal combustion engine and the electric motor. At this time several advances on chemistry also allowed advances in several industrial sectors and even started the Pharmaceutical Industry.

The hallmarks of the second industrial revolution were:

- Decentralization of the power source (due to the internal combustion engine)
- The Production line (Henry Ford being the important name)
- Low cost products affordable by employees
- Automation and automated flow of materials and information
- Development of the Chemical Industry
- The use of Sciences to create knowledge
- Higher level of necessary skills, needing better quality and total reach of the elementary school on the social fabric

Engineers, at this time, could not innovate without a solid culture based on sciences. Moreover, the complexity of the production line changed into “scientific” the empirical managerial techniques prevailing in the XIX century. This blend of technical and managerial revolution on the production techniques needed a new breed of Engineers with full command on sciences and on managerial techniques. This period that prevailed up to the 70’s in the recently passed century saw several movements that changed Engineering Education. Particularly after the Second World War, the advances in microelectronics extended dramatically the scientific aspect of Engineering Education and of Engineering Research, underlining the ties between the research universities and the productive sector [4].

The economic value of knowledge became evident, and the Schools of Engineering changed their former closed environment into open knowledge factories where research and education became the cradle of innovation.

Only the countries that universalized, even partially, the elementary school could lead the second wave of the industrial revolution. The basic skills presented by workers in this new period were based on full literacy.

The further miniaturization of electronics and the popularization of the microcomputer and the association of microelectronics with optics and the consequent advances on telecommunications gave birth to a completely new environment for innovation due to the new capillary human interaction and the widespread presence of information. A new wave of the industrial revolution started between the 70’s and 80’s of the passed century.

The hallmarks of the third industrial revolution were:

- Decentralization of the “intelligence” (due to the astonishing evolution of computers and computer sciences)
- Reduction of the intrinsic value of the raw materials
- Microprocessor and machine decision making and control becoming more accurate and faster than the corresponding process by human beings
- Liberation of the human beings to full use of their creativity as an important professional tool
- High value of the innovation (new products with economic value) not only associated with large industries, but also to small business in the service society
- Larger social reach of higher education and capillary application of research results facilitating the use of knowledge for innovation, in a process not always associated with large investment of capital

The Present Thrust on Globalization is Part of the Third Industrial Revolution. The social consequences of the capillary distribution of information follow the capillary distribution of the decision-making mechanism. The consequence was the strong increase on the importance of the individual, either as a consumer or as an entrepreneur [5]. As the human activities reach planetary dimension, the smaller element of the society - the individual - becomes the center of the production process.

LOOPS OF INNOVATION

The need for innovation in the productive sector is now much more complicated, presenting itself in several loops. We will discuss two extreme situations of this process, besides its consequences on the educational process for Engineers.

The capillary mechanism of communication and the fierce search for market share of the international companies started a process of outsourcing within the productive sector. The outsourcing mechanism fueled the already booming service society, where myriad of small business found their niches of opportunities with knowledge base enterprises.

This small knowledge based business find a safe cocoon within the new booming process of incubator development within the universities. Besides the profound modifications of the University fabric due to this important process, a new concept of research aiming short-range result developments.

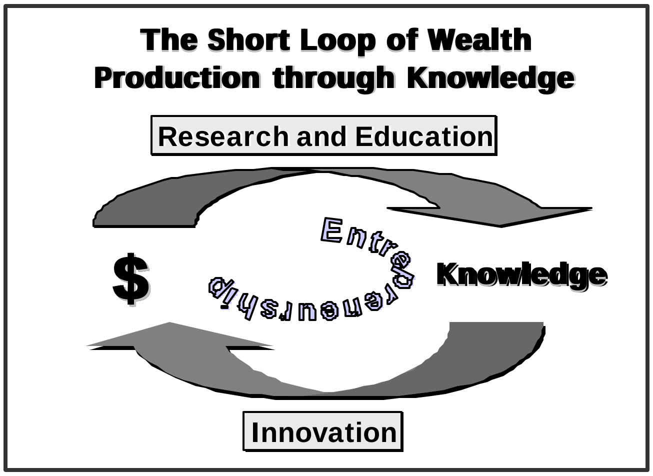

FIGURE. 1

The traditional concept of basic research creating new ideas followed by applied research and finally the product development is not adapted to this short loop of innovation. In figure 1 we present a view of a mechanism where money is applied to generate knowledge through research (new ideas) and education (development of minds). The acquired knowledge may produce wealth short after through the innovation process.

Research in the presented short loop may be an activity that unites two or more well developed ideas. Michael Gibbons describes this type of research as a "second mode" of research [6].

INFORMATION, BIO AND NANO-TECHNOLOGIES

The beginning of the XXI century, nevertheless, heralds the development of new technologies like nano-engineering, a further presence of information technology and the appearance of engineering technologies based on new biologic findings, the biotechnologies. These three fields behave differently from the point of view of loops of innovation.

The information technology has, in the beginning of this century, a highly structured production cycle, based, essentially, in new business, in logical or commercial ideas and in the finding of new products. Bill Gates says that there was no essential new scientific invention in this subject after the seventies, when the computer nets were defined. In his opinion, the development of information industry depends only on the capacity and price of new electronic devices, i.e. on nano-technologies. Gate's opinion does not mean the end of research in information science. Remember his joint-venture with Cambridge University to solve difficult and still open problems in pattern recognition from linguistic specifications. But Gate shows the real situation in software industry. In this moment, almost all new products are specific applications to specific needs or improvement of older ones. They depend mainly on new ideas and are accessible to small business, which is more able to find small niches near consumers. In other words, wealth production has its big ways well known, the problem being understand consumers needs.

For that, this industry is organized in a modular system organized in many levels, beginning on operational systems, crossing intermediary systems, as browsers or simulation integrators and arriving to specific applications. The typical investment for such developments goes from tens to hundreds of thousand dollars. The Linux system is a good example of such small and successful investment on the core of this industry. Today, almost all incubated shops in the world work with information technology and, in spite of big business, Microsoft position is not warranted. Remember that patents protection is very difficult because it is very easy to copy or to remake.

The multi-level and modular organization of information technology industry broke the innovation loops in many small loops, allowing small business and engineers' initiative. This situation is reinforced by the relative easiness to grasp the information science and technology, which depends mainly on logic and strongly simplify the information technology engineer formation. Entrepreneurship becomes the key word.

The innovation loops on biotechnology are longer than the ones in information technology, and we are seeing new scientific findings and inventions daily. The investment to develop a new vaccine is about ten million dollars, and for its production and commercialization about three hundred million dollars. The production of Polly (the first transgenic sheep clone producing medicinal proteins in its milk) consumed less than ten million dollars, if we consider the cost of Dolly and theirs preliminaries. But production processes are almost well known, almost all equipment use conventional technologies, and biotechnological industry is also structured. From equipment industry (Beckman, Biorad, Farmacia, Zeiss, etc.) to medicine laboratories (Glaxo, Merck, Hoestch, etc.), there is a lot of opportunity to small business developing innovations with ideas and small investment. Notwithstanding the long time for maturation of vaccines, medicines or transgenic species, some of new genetic modified or transgenic innovations appeared on small shops, as a recent number of La Recherche showed. Moreover, small laboratories are the clue to medicine distribution in the Third World, and they are possible because it is easy to break patents and to develop new production processes. Also, it is easier to big enterprises in others industrial sectors (petroleum, e.g.) develop theirs own specific biotechnologies (using innovation dedicated small shops) than to buy known ones.

However, in biotechnology, scientific research and innovation are really very close. The wealth production drives directly the research in this area: applications to wealth development are very evident in biotechnology. Therefore, biotechnological engineers need a strong and very special formation, from scientific aptitudes to business ones, from physic-mathematical knowledge to biological knowledge. Remember that those fields work on different operational paradigms. On one side the mechanical paradigm; on the other side the biological paradigm. A few bacteria are not negligible because it quickly multiplies in favorable ambiance (it is not a usual thinking to an engineer). Species evolution is a "philosophical" idea but it is the key to understand microbes and virus’s resistance or the intrinsic difficulties and ways of biological processes. Biology does not reduce to Physics and Chemistry.

Nano-technologies, at this moment, have only long innovation loops that are not accessible to small business or to incubated shops. There is no modular or multi-level organization. It will be possible? Contrary to the above presented short cycle of wealth production, the nano-technologies are complex, require a much longer maturation process and much larger investments, typical on the several billion dollar range. Patents are not broken: this is not possible due to the heavy and costly scientific development needed. Moreover, there are not standard procedures or process in this technology. There is no established technique. Although small enterprises may take advantage of the results by finding niches of opportunities for applications, the typical research mechanism of the long loop of wealth production represented by these new technologies need effectively new findings. The knowledge in this area is full of blanks. To pass from micro-technologies to smaller scale technologies needs, in this moment, to solve hard scientific problems. Innovation in this subject means big investment and sound scientific knowledge. Therefore, the engineer education to work with nano-technologies is highly different from the two cases considered above. This engineer will mainly work with the mechanical paradigm, but in a scientific team. The initiatives are more near to Applied Physics than to business. The needed scientific formation is very sound and prevalent to business formation or traditional technologic formation, the inquiry aptitude and the skill to work in scientific teams are essential.

Both the long and short loop of wealth are firmly dependent on engineering capability, and need specific measures on engineering education redressing.

ENGINEERING EDUCATION

During the several meetings of the International Conference on Engineering Education, the new profile of the Engineer that should be forged by the Schools of Engineering was thoroughly discussed by many authors. A particularly interesting explanation was given in the Key note Speech to the 1999 version of the International Conference on Engineering Education by professor Georges Lespinard [7].

In the presented conception, the Engineering professional must develop his or her skills on technology, sciences, management and even human and social sciences. This last aspect becomes more and more connected with an international vision of the productive process. Each School of Engineering will balance their course in order to cover all those four axes of human knowledge according to the scope, mission and vision of each School.

The entrepreneurial behavior is developed by hands-on-design disciplines. Modules of entrepreneurship should be taught also in disciplines that forge market vision and global vision. All those disciplines are taught in parallel with the usual Physics, Mathematics, Chemistry and Computer Science blend of the freshman and sophomore years, in a concurrent way. Moreover, the strong presence of Graduate courses and active research facilities is fundamental as a relevant environment for an effective development of new ideas, fundamental for the entrepreneurial engineer.

The development of solid culture on basic sciences and a strong vision on developed technology and an easy handling of the new aspects of developing technologies, nevertheless, are assets that are very important to the development of the research abilities typical of those involved on the long cycle of wealth development. Sequential disciplines within an environment of research universities and graduate courses are fundamental to the formation of this breed of professional.

CONCLUSIONS

The present thrust on globalization is a consequence of the third industrial revolution. In this historical moment, the process of innovation responds to an interesting paradox: More the process of globalization develops, more the

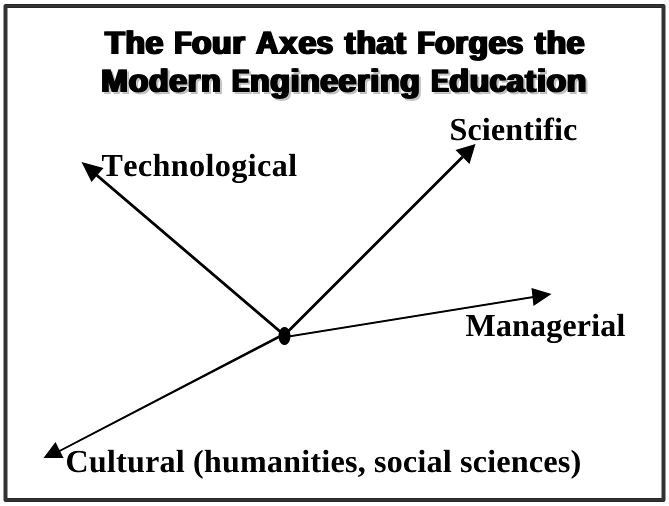

FIGURE. 2

industrial production aims the smaller element of the society – the individual.

The present industrial society deals with two extreme mechanisms of innovation:

1. The short loop production of wealth through entrepreneurship, where research is characterized by a suitable blend of well developed findings into innovation
2. The long loop production of wealth where the new products are the result of a long and expensive process that starts with basic research.

The future engineer will be always dealing with one of those extreme situations or any intermediate one, and needs a strong cultural basis in order to deal with any new situation.

The school of engineering should be prepared to offer a rich environment where education and research are blended in the complex process of mind forging.

The necessary blend of concurrent and sequential disciplines is fundamental to foster the engineers that are necessary to develop the several types of loops leading to wealth whose two extreme cases were depicted above.

The engineering career is not singly defined as engineers that will work in small corporations as entrepreneurs or those that will be prepared for a life long career in large corporations.

Most probably the future engineer will spend part of his or her life in one of those two situations or in intermediate situations were the entrepreneurial and scientific behavior will support a superior professional.

The blend of the educational and research aspects of the Schools of Engineering tend to be more and more the two sides of the same coin.

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