INNOVATION AND ENGINEERING EDUCATION

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***Abstract** - Engineering Education is a much more recent toil as a higher education process then, say, Medicine or Law. The importance of Engineers, as practitioners, grew along the now more than two century long continuous Industrial Revolution. The results of the Engineering practice have been strongly marked by factories and the evolution of the industrial production, these facts defined by the processes in use and the growth of wealth. The shape of engineering practices has changed dramatically along the XX century. Engineers evolved from high level technicians to experts in sciences and managers. All these changes were followed by profound modifications on the School of Engineering but all them kept engineers as high level employees of large enterprises. The present moment, characterise by decentralisation of the decision process, tend to increase the number of small firms and underline the importance of the entrepreneurial engineer. This paper discusses the importance of innovation in the production process and the role of engineers in the knowledge society, as well as the new aspects on engineering education connected to these new roles.*

Index Terms – Engineering Education, Innovation, Modes of Research, University Mission.

INTRODUCTION

Engineering practice has changed a lot since the end of Second world War, either by technologies innovations and by the higher extension and complexity of the problems engineers have to deal with [1]. They were kept from technical and specialised functions to manage occupations and activities involving firm development for which their scientific and technology basis are determinants. For instance: in the Manhattan Project, the production stage were given to Dupont de Nemours' responsibility, who had recently moved out of nylon industry, based on high pressure chemistry. If we move together with the discussions between the Dupont chairman and Fermi, the creator of the scientific part of the project [2], we will see the disagreement between the equation culture (brought by Fermi, for whom Los Alamos Project was only an application of knowledge on Physics) and the plant culture (brought by Dupont, who saw Los Alamos as a process of output a product with deadlines, limitation and uncertainties). Another excellent example can be spatial competition, where Von Braun's vision of production process was determinant.

Most recently, the decentralisation of decision and production process, as well as the new ways of production (modular industry, outsourcing, globalisation), and the post-industrial society lead to new engineer activities. Not only the engineering job market had extended far from the earlier technical definitions – that are still used as the purpose of engineering education – but also an increasing number of small firms with technological basis began to demand an entrepreneurial engineer, who must have management basis and must work with development and innovation. Examples of these are the continuos increasing number of engineers at financial market, at management of technological based organisation, at production process and at computing areas.

The age of knowledge, where the necessary innovation has to be popularised to be the crucial part of the industrial development, coincides with the age of globalisation , where competition happens on planetary scale [3]. Good education, making entrepreneurial engineers who will be prepared for innovations (what imposes scientific based solutions), increase production processes understanding with management vision, is the only way of developing the top industry and satisfy the post-industrial society needs.

The School of Engineering response must be reflexive: dealing with the new innovation paradigm within undergraduate courses of engineering. Innovation is the most recent education paradigm. Facts, like the modern educational methods [4] focused on individuals and on learning, confirm the absorption of this new paradigm that tends to treat technical and scientific questions as part of a context that requires a deep comprehension of social, economical, cultural problems.

CONCEPTS AND DEFINITIONS

Before starting the discussion about how this new statement can change the Engineering School courses, justifying the title, it must be important to fix some concepts. We will call <u>invention</u> (or scientific discovery) the characterisation of new knowledge that can be used to increase welfare, usually a direct consequence of scientific research. An <u>innovation</u> is a novelty to the market with commercial value, still depending on future development as well as its social

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acceptability (what includes tests, studies on environment, development of distribution process, etc.).

Another important distinction is given by [5]:

- Immature technologies: associated with inventions and with fundamental research, of large risk and large impact, that can change production processes; still needing extensive investments and a large maturation time;
- Increasing technologies: associated with demands not yet satisfied, still needing the improving of products and processes, also demanding extensive investments, but needing less time for maturation, although representing less risk but posting high impacts;
- Fully developed technologies: associated with the necessary efficiency needed to keep the industrial competitivity, leading to an incremental research, of low risk, with small but essential impacts for productivity and demanding small investments.

Examples of immature technologies are nanotechnologies. The large gaps of knowledge in this topic turns every research in a deep scientific work, demanding the resolution of fundamental problems on physics. There is no standard technology or established procedures in this process. Consequently, investments could be around one billion dollar. An increasing technology is biotechnology, with industrial more clear and fixed processes, and investments can be valued from ten (as in vaccine production) to hundred million dollar (the creation of a new vaccine), allowing operation with small sums (as the production of generic medicaments), associated with more usual technologies. An example of a fully developed technology is software engineering, which, even admitting some difficult open problems (recognising natural language models, for instance), have been extensively used in the post-industrial society, that Considers the needs of consumers, generating micro-firms, opening new niches and allowing small investments, as said by Scavarda do Carmo et al. [6].

A third concepts deals with the place and the methods of researching and development [7]. In a first way of knowledge production, knowledge would be produced at Universities and Research Institutions and, later, it would be absorbed by Industry, where it would be "engineered" in order to become a product. This serial way, for instance, was used in the development of thermoelectrically produced electricity. In a second way of knowledge production, the industrial needs are the starting point of a series of activities, with or without any academic research. This was the case of the creation of hydroelectric plants, as well as the nylon and other synthetic fibre production.

Obviously, the roles and the interests of Universities, Research Institutions, Industry and Government and its Agencies are different according to the kind of developing technology, either if it is an invention or an innovation, and according to the risk and cost represented. It will determine the way of production and the University-Industry relation. We must add to those differences the culture in each firm or country, that could be positioned against every risk or investment for research or innovation.

INNOVATION NETWORK

University enterprise incubators and sponsorships for discovery and inventions are part of the first way of knowledge production, emphasising entrepreneurship and the creation of new innovations network [8] that can keep industrial investments to transform invention in a concrete product. The size of this network can be represented by short or long (according to the involved technology) lops, but it is characterised by the presence of key members: the University, the entrepreneurs and those who will "engineer" the discovery until it can be really useful to industrial processes. Clear examples are Apple and Microsoft, as well as some firms based on biotechnology. In any case, those firms started very small and grew to gigantic seizes.

The second way of knowledge production drives the innovation network into the needs of industry. It means that knowledge creation can happen at the University (industrial and academic labs working together) by industrial demands or directly at industrial laboratories. Examples are CENPES (in Brazil), AirBus (in Europe), IBM and Lucent (nowadays).

The second way of knowledge production leads to some changes in the university model (emphasising an University of Research) and creates the problem of different ethos living together in the Universities (Aranha et al., 1998). One of the factors in the root of this second way is the absorption of researchers, graduated in Universities, by the industries, a processes that gave origin to the fast growth on the number of Research Universities after the Second World War (Gibbons, s. d.).

THE IMPORTANCE OF GRADUATING AN ENGINEER FOCUSED ON INOVATION

The traditional undergraduate engineering studies does not prepare students to the new roles that are imposed by the starting XXI century. An interesting historical retrospect of the several and successive undergraduate engineering courses on Anglo-Saxon countries is found in [1]. The Brazilian and European situations (excepting France and its peculiarities) followed similar patterns.

A summary of these new roles in education within the Schools of Engineering are:

- A wide and integrated scientific basis, allowing the development of team work that leads to undergraduate studies that allows future development of the still immature technologies;
- Full understand of the ecological impacts of inventions;
- Solving problem skills;
- Market vision that anticipates social and economic needs as well as an entrepreneurial mind

- Personal skills for creating innovation networks and working in the second way of knowledge production.

The feelings of those new roles and the necessity of engineering education changes caused the appearance of new institutions like the American Society for Engineering Education - ASEE, the "Societé Europeene pour la Formation des Ingenieurs" – SEFI, the American Board for Engineering and Technology - ABET and the "Associação Brasileira para o Ensino de Engenharia" - ABENGE and the appearance of national programs involved with the study of how to educate this student of engineering. Important cases were the North-American programs, supported by National Science Foundation - NSF and the "Reengenharia do Ensino de Engenharia" program - REENGE, in Brazil. See[6].

HOW TO EDUCATE AN ENTREPRENEURIAL / INNOVATOR ENGINEER?

Several different methodologies had been presented to address this problem, as we can see in the proceedings of the several International Conferences on Engineering Education - ICEEs, International Conference on Computational Engineering Education - ICECE and of the conferences organised by the American Society of Mechanical Engineering - ASME. Methodological and/or structural changes in engineering schools have being facing several difficulties. In Brazil we find legal difficulties, connected to a limited traditional thinking, and the limitations on the continuity on the Government policies that finally abandoned new ways for fostering education culminating with the end of the REENGE project. This project, however, even short lived, developed radical changes on educational aims, the used methodologies and pedagogical proposals in Engineering Schools. Enterprise incubators had been created, some of them acting inside the university as cradles of enterprises.

Some mechanisms to educate the new engineer are the creation of:

(a) Hands-on courses, competitive teaching (as we can see at Engineering Introduction disciplines).
(b) Flexible curricula, anticipating management formation.
(c) Periodical professional training for students involving firms and industries, that familiarise students successively with the industrial working places, a working position and with the realisation of a complete project of engineer.
(d) junior Enterprise, a firm constituted by students and supported by teachers.
(e) Enterprise incubators working from scientific and development activities inside the Engineering School, aggregating recently-graduated students.
(f) usual disciplines dealing with costs, production processes and how to "engineer" products.
(g) Hands-on and "production process" disciplines, focused on how to find market niches, and how to develop new products, patents and intellectual property to satisfy the necessities of these niches.
(h) International formation, that develops the familiarity with more than one culture, what supposes the command of other languages and other countries. This international formation must begin at School (with disciplines of Geography and History, for instance) and continues with international exchange, aiming the development of degrees bestowed by universities in two countries.

But the central point of those changes is to establish the post-industrial paradigm in the realm of the University (specially in the School of Engineering), spanning habits necessary to attend the needs of the production and service system (using the second way of knowledge production), but comprehending the university – academic context (first way of knowledge production). Enterprise incubators together with a new university structure that contains specific laboratories that attends the university needs and also the industry's needs. One example is the CRITT, in France. Consulting firms, which act as academic and production system mediators, are not always fully accepted by the academic society but, even thought, are essential in the establishment of new paradigms. This approach of the academic ethos with the production sector through the presence in the campus of the enterprise incubators changed the 1st way of production [7] and defined new academic activities that characterises the 2nd mode of research, changing in many ways not only the university mission but also the related academic activities.

Furthermore, those changes (trying to educate entrepreneurial engineers) must be in equilibrium with regional differences as well as with the different titles demanded by the different acting areas and technologies that are used. Thus, from a professional devoted to the area of computing, we expect a wider market vision then from a professional devoted to nanotechnology. [9].

As a consequence, it is possible to present the following proposals:

- <u>Foster education for innovation</u>: supporting the study and the development of engineering education (seeking for innovating engineers) [10].
- <u>Foster University-Industry interaction</u>, through the creation of research clusters and through the development of Schools of Engineering that generates innovation networks, as described above.
- <u>Foster international formation</u>, with a possible support of multinational firms.
- <u>Develop Flexibility</u>: the education for innovation must be flexible in order to attend the different production lines, with their own needs. It is necessary, nevertheless, to develop each school's vocation, comprehending each region vocation and tradition. The curriculum for developing immature technologies is different from the one that allows students to absorb fully developed technologies. Research Universities are aligned with the

new modes of research. The non research Schools will choose to limit their teaching abilities on fully developed technologies, emphasising management formation.

STRUCTURAL AND PARADIGM CHANGES

The need for University structural changes becomes obvious in order to deal with different scientific research ethos, thus contributing effectively to the technology development that characterises the last decade of the past century and seems to be dominant in the starting years of the XXI century. The University present structure is the ideal place for development of the first way of knowledge production [7]. It is important to emphasise that most of the present universities were created outside the context of the production world.

Realities that are outside the university walls, such as social needs, market demands (actual users of inventions), are easily absorbed within the university environment by students in university incubators. Clusters are more complex mechanisms where education and research activities integrates with the job market in a natural way [10], considering that labs and agreements mentioned above are also usual "facilities" of this environment Incubators and clusters are modern society mechanisms that tend to eliminate the present paradigm that differentiates the real world from the academic world. Furthermore, clusters and incubators are mechanisms of transformation of knowledge into wealth.

The prevalence of academic ethos leads to excessive scientific research valuation, measured by specialised periodicals publications. The common ways of sponsorship increase excessively the researchers' curriculum in spite of development activities, so as proposals based on industrial interests. It must be observed that when curricula are used as the most important way of individual analysis, in time of changing paradigms, this analysis can become, simply, a way of measuring past successes, obstructing the jump for the future. But we can't deny that, without a good curriculum, we don't have any guarantee that the work will be effectively well done. The LATTES curriculum, used in Brazil, for instance, contemplates the technological production (patents, prototypes, etc.), although it doesn't make clear how much involved are the researcher with society and the industries, or even if the patents actually correspond to Brazilian industry demands. Maybe, under certain circumstances, evaluators must keep information from other parts of the curriculum, or even complement the traditional curriculum.

The "publish or perish" paradigm leads to interdiction of direct or indirect sponsorship for innovations development in industry (second way of knowledge production), [7] - influencing Brazilians legislation and the management practising that makes this kind of interaction becomes difficult. This paradigm also makes some researchers loose their interest in possible innovations, putting them in the other side of the balance [8]. The award system of the university academic world should change in the Engineering School, so that the new activity attribution systems could be taken into consideration. It is necessary to assess the Engineering Schools by their position within clusters and by technologies developed by them, remembering that the traditional Research University ideal taken as the only allowed ideal (as in Brazilian case) jeopardises the development of the productive system.

REFERENCES

[1] Prados, J. W., Engineering Education in the United States: Past, Present and Future, *Proceedings of the ICEE98*, CDRom. Rio de Janeiro: PUC-Rio, 1998.
[2] L'industrie nucleaire: un cas d'étude, *La Recherche*, Juin 1998.
[3] John Naisbitt, The Global Paradox. Avon Books.
[4] da Silveira, M. A. and Scavarda do Carmo, Luiz C., Sequential and Concurrent Teaching: Structuring Hand's-On Methodology", *IEEE Trans. Education*, Vol. 42, n. 2, pp. 103-108, May 1999.
[5] Bardy, L. P., Financiamento de Projetos de P&D, *in* Sandroni, F. A. R., editor, *Cadernos de Tecnologia* Vol. 1. Rio de Janeiro, Instituto Euvaldo Lodi (FIRJAN), 2001.
[6] Scavarda do Carmo, L. C., Pimenta-Bueno, J. A., Aranha, J. A., Costa, T. S. da, Parise, J. A. R., Davidovich, M. A. M., da Silveira, M. A.; The entrepreneurial engineer - a new paradigm for the reform of engineering education, *Proceedings of the ICEE97*, Vol. 1, Southern Illinois Un. at Carbondale, Carbondale, Illinois, USA, 1997, pp 398-408.
[7] Gibbons, M., *Higher Education Relevance on the 21st Century.* Washington: World Bank, s. d.
[8] Aranha, J., Pimenta-Bueno, J. A., Scavarda do Carmo, L. C., da Silveira, M. A., Entrepreneurship Formation: The PUC-Rio Experience, *Proceedings of the ICEE98*, CDRom. Rio de Janeiro: PUC-Rio, 1998.
[9] Scavarda do Carmo, L. C., Costa, T., Da Silveira, M. A**.,** Engineering Education, The Fast Technological Revolution and the Innovation Loops. Proceeding of the *International Conference on Engineering Education* at Oslo, August, 2001.
[10] Michael Porter. Clusters and the New Concept of Competition. Harvard Business Review, November – December 1998.