Engineering Education as a Logical Body for Modern Generalist Professionals

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Abstract *— The development of telecommunications and information technology led to the fast growth of global activities absorbing the large -scale use of continuously changing technology and related updating research. Th is fact extended the career of the Engineer away from traditional areas such as construction, urban infra -structure, or industry -related technology and production to new challenges such as urbanization, education, logistics, the environment and deal with subjects as distant to the traditional engineer as safety, entrepreneurship, poverty or even corruption. The new professional needs encompass competencies such as technical and scientific knowledge, managerial skills and the comprehension of cultural aspec ts. The global economy is visible to the engineer through the new production mechanisms; across the border exchange of materials, products and information; job migration and also the continuous change of the industry market share, even in places that are distant from the original area of production. Engineers have become engines of globalization and face challenges that are far beyond the technical and scientific aspects that characterized the engineering profession in the last decades of the past century . This paper discusses the necessarily changing aspects of Engineering Education led by the new realities, the categories of the competencies needed in order to be a competitive and socially responsible professional, and possible mechanisms to form a mode rn professional. The formation of the new Engineer is presented as a logical body that is necessary for any modern professional, even the one that will necessarily tackle activities that a short time ago were not related to the Engineering profession. Ess entially, the new engineer is characterized as a problem -solver, working on technology -based problems in a social, economic, ecological and political environment. In this context, technology is seen as a social practice that needs logical, mathematical and physical modeling, in addition to the development of systematic methodologies, software, algorithms, or physical devices to be improved, under criteria to be given or to be discussed within market realities. The production and use of technology defines n ew activities and professional functions, which are distinct from the ones to be performed by lawyers, physicians, educators and other professionals, in spite of eventual team working. This paper also presents a holistic vision of some aspects of the curri culum of Schools of Engineering as well as educational tools that must be taken into consideration when this new breed of cross -disciplinary professional is educated within Schools of Engineering. Since the professional activities become very distinct alo ng one's lifetime, professional titles could also be distinct from the name of the Higher Education title obtained in the School, and, on the other hand, the new competencies taught in the School of Engineering became relevant for a new breed of generalist professional not directly interested in the title of Engineer. A brief discussion is also conducted on the delicate question that a professional that is an Engineer with these extended activities could hardly be classified as Electrical, Civil, Mechanical or have any other traditional denomination. The questions posed should be discussed within professional organizations and even accreditation boards.*

Index Terms *— Engineering Education, Logical Body, Modern Professionals.*

INTRODUCTION

This paper is based on the experience acquired by its authors in the course of their engineering teaching activities at PUC-Rio and on their attempts to associate the challenges of modernity and of the present-day job market with the development of a generalist profile for engineering professionals. Today, in addition to the technical tasks that are usually attributed to them, such professionals are expected to participate in the development of competitive strategies and in the administrative management of projects. These new activities make it necessary to consider the ethical and social components that regulate their actions.

The educational profile for engineering professionals discussed here is not meant to exclude, but rather to complement an

entire typology of educational profiles ranging from engineers with a basic technical specialization-level education (the "shop floor" engineer and the maintenance engineer) to the generalist engineer with a managerial vision - not to mention the different types of specialization areas that become more numerous as the technological arc expands. The fact that this increase is not limited to the technology-related specialization areas, but also incorporates the set of functions and social roles performed by engineers has led to the use of the concept of an "extended" job market that lies beyond the one that corresponds to the performance of the traditional technical functions. Engineers are being called upon to organize a huge variety of tasks - whenever organized, systematic and systemic reasoning with a technical and economic vision is required - that comprise the essence of current productive processes, tasks that are immersed in and depend on the social and political context and that are not performed by force of regulatory requirements, such the environmental ones.

The existence of such diverse educational profiles demonstrates the need for a curricular option on the part of engineering schools: each school must choose its own educational profile according to its audience and to the part of the job market it wishes to reach, recognizing the fact that it is impossible to cover profiles that differ too greatly at a single campus because they will require different teaching methodologies.

In order to explain this phenomenon more clearly and at the same time to capture the essence of this type of education that leads to professional success in activities that are beyond the technical tasks originally attributed to this profession, the notion of engineering as a logical body was created, a congregation of the complementary cognitive elements that have the power to increase, not only these professionals' interpretive and representative capabilities, but also their ability to transform intentions into projects and the latter into actions, organizing and managing the social production processes.

THE CONCEPTION OF A LOGICAL BODY

The notion of a logical body is not modern, despite the fact that it is substantially different from the one demanded by the challenges of modern society. It was first identified in the first millennium of the Christian Era, when liberal arts were introduced in schools. The work of Marzianno Capella in the fifth century AD exerted direct influence on the medieval classification because it established a fixed number of seven such disciplines, which were subdivided into the Trivium, a nucleus of arts that were categorized within the literary sphere, comprising grammar, rhetoric and dialectics, and the Quadrivium, that incorporated the arts of a scientific nature and comprised arithmetic, geometry, astronomy and music. This educational structure became the preparatory subject matter for courses in law and theology and was inserted in the university curriculum for students from 14 to twenty years of age[1].

An analysis of this logical structure and of its application at the time demonstrates that the function of this cognitive base was that of supporting an erudite profile in a way that would enable students to express themselves properly in the environment in which they were inserted, where they would display an extensive cultural knowledge as a sign of their social status rather than for some possible practical use.

Today's challenge is much more complex. The conceptual base that has proved to be necessary nowadays cannot be limited to mere erudition. Instead, it is an instrument for interpreting reality with a view to changing it. Or, according to Waddington (1979)[2], an instrumental contingent for thought, that is, a set of models that are able to deliver the ability to interpret and consequently represent and act upon reality when articulated.

It may be said that while in the Middle Ages, competency was measured in terms of erudition, the present moment demands a more complex conceptualization of competency. For the purpose of this paper, we have adopted an adaptation of Perrenoud's vision, according to which "competency" is the ability to mobilize and articulate a body of learning (or knowledge), skills (or specific competencies[3]), aptitudes and attitudes in order to effectively solve new duly contextualized problems in a sound and conscious manner.

Broadly speaking, social commitment and the ability to interpret and represent reality are identified as invariant components of this competency. This requires an educational perspective that focuses on the ethical aspects of an engineer's activities from the social as well as the professional and environmental points of view. Finally, and this is certainly where the clear distinction in relation to the medieval logical body lies, these engineers must develop an actual capacity for acting upon and modifying the reality in which they are inserted. Such professionals will be required to have the ability to measure and manage their own performances and therefore, to develop instruments for perceiving and anticipating probable change, in other words: they will need to be competent enough to elaborate plans and to make projects materialize; they will need enterprising capabilities to a degree that will allow them to seize opportunities and generate business, as well as the kind of administrative and managerial flexibility that will enable them to cope with a rapidly and constantly changing world.

Based on what has been mentioned above, it can be said that the logical body of a profession is a set of types of knowledge (empirical or theoretical, descriptive or logically structured, conceptual or procedural) that are interrelated and referred to their concrete use, and are associated with the professional aptitudes, attitudes and problems that require them. For the sake of demonstrating the extent of this definition, the logical body of engineering (to be discussed below) includes, for example, a well developed capacity for critical thinking, the ability to represent socioeconomic situations and the ability to

represent and modify production processes or processes for solving company-related problems (that include managerial processes, supply chains and socioeconomic analyses with a view to future undertakings).

Not all professions have come to have a logical body. In fact, it is possible to study the manner in which the logical body came into existence and the changes it has undergone with the passing of time. For example, in the medical profession, this logical body began to take shape at the end of the 19th Century through Claude Bernard and his studies in histology and was further developed as a result of the works of Koch and Pasteur. However, it was only at the dawn of the 20th Century that medical schools - the German schools at first - began to use this logical body as a basis for their courses and as a result, removed this type of learning from an empirical swamp where the fog was so dense that it allowed U.S. President Andrew Jackson (1828-1836) to argue this profession did not require any regulation at all[4]. It should be observed that the logical body of medicine has undergone profound change in the past few years on account of the discoveries that have been made in biology, a fact that will necessarily lead to an extensive reform in the education of practitioners in this area.

Law and engineering are among the other professions that already have a logical body. The latter's logical body began to assert itself at the beginning of the 19th Century based on the needs that arose from the Industrial Revolution and was organized towards the end of that century in different sets according to the expected extent of the professional activity. Notice the possible long- (Technische Universitäten) and short-term (Fachohschüles) educational models in the German system. At the end of World War II, these logical bodies were reformed once more (at least in the developed countries), and now, they are again facing the need for urgent redefinition so as to be able to cope with post-industrial society and with the aforementioned expansion of an engineer's functions and social roles.

THE LOGICAL BODY OF ENGINEERING

Engineers are problem-solvers and interfere in technology-related social practices that affect not only the production processes, but also the products themselves, their use values and the social values with which they are associated. In the post-industrial society, the engineers whose work is related to the development of competitive strategies and to the administrative management of projects and production processes and always strive to achieve an increase in productivity in a way that suits a view of the future that encompasses possible risks (economic, environmental, etc.), are much more numerous than those whose work is directly associated with production processes for materials and equipment or with the maintenance of such items. Research carried out at any major engineering company will reveal career paths for engineers which already start out with surveys of market possibilities and specification analyses instead of proposing the traditional trajectory of technician-head of department-manager-director[5]. This the dominion of the "service society", where information and the ability to absorb, generate, manage, transform, represent and divulge knowledge and information has become a major asset for companies and countries.

By restricting this study to the generalist engineer endowed with a managerial vision and an enterprising spirit, it becomes possible to reduce this logical body to a particular set of competencies, attitudes and aptitudes to be developed along the functions, domains and activity sectors according to the specific interests of the engineering school (considering its audience, the part of the market it wishes to attain, its limits and opportunities, its history and traditions). However, the logical body must consider this current expansion of the engineer's sphere of activity, that is, it must transcend technical education by preparing such professionals for novel and as yet unimaginable functions and endowing them with consciousness and the resources for an ethical social performance.

The list below may be mentioned as an example (an adaptation, for the sake of convenience, of the list formulated by the École Centrale de Lille):

Competencies: ability to	Recognize problems and know how to formalize and represent them with a view to their solution while recognizing the means and limitations in technical, business and social environments; master the complexity of the real; search for, represent, analyze and communicate knowledge and actions in view of a specific purpose; relate means and ends, different types of knowledge between themselves, reality and theory by means of rationally constructed models; generate business initiatives; develop a strategic vision of the company; decide and act; exercise critical thinking; innovate; develop oneself as a person; be open to culture in general; make professional and personal commitments; be a team leader and do team work.
Knowledge	Mathematics and logic, natural sciences, basic principles and methodologies of social and human sciences, knowledge about the company and its activity sectors, management and situational analysis processes, engineering sciences.
Aptitudes	Capacity for abstract thought, intellectual acuity, capacity for work, and strictness.

TABLE 1
LIST OF COMPETENCES BY THE ÉCOLE CENTRALE DE LILLE.

The list of competencies (developed by the École Centrale de Lille) could be opened as follows:

Conceive	Formulate the problem
	Formalize it
	Model it
	Imagine solutions based on the model
	Choose the satisfactory solutions
Concretize	Make a model become realistic and ensure that it may be concretized. Experiment with it.
	Produce it
Innovate	Mobilize/stimulate personal or group creativity
	Listen to what the external environment has to say
	Focus creativity on an objective fact
	Produce solutions
Encourage, lead	Explain a project clearly and emphasize its value
	Stimulate the dynamic of a project
	Ensure the sequence and follow-up
Organize	Apply the suitable means and methods for ensuring the exchange of information/instructions between a system's actors
	Regulate and control the evolution of a system from the time it is being assembled to the moment the project achieves its objectives
Communicate	Exchange information in a clear and precise manner
	Listen to what collaborators have to say
	Develop an ability to come into contact with people
	Organize the circulation of information by means of all methods and material resources
	Present arguments for project guidelines
Educate	Select the persons that are going to take the course
	Elaborate a plan for the course
	Conduct the entire course or part of it
	Assess the increased human resource potentialities

TABLE 2
THE OPENED LIST OF COMPETENCES BY THE ÉCOLE CENTRALE DE LILLE.

When the list for knowledge is opened, it may be observed that in addition to the habitual basic sciences included in an engineer's education, other items are required, such as discrete mathematics and the principles of biology, a formation in project-related art skills (the sciences of the artificial, in the words of H. Simon), and the mastering of skills related to the use of communication tools and of tools for representing reality - which include the mastery of foreign languages and cultures, of models and modeling techniques, and of graphic and iconic language, the ability to present ideas and to communicate, and the ability to consider a message from the standpoint of the interlocutor - to whom it is addressed.

Attitudes and aptitudes come next: professionals must open up to the world, understand it (which requires an all-round culture and experience in representing different types of knowledge), and have an enterprising vision oriented towards finding business niches (in which case they must have a good understanding of the company, of the society in which it is inserted and of its values) and towards the construction of an attitude that is based on acknowledging the fact that each person is responsible for his/her own future (responsibility in its full sense).

But the essential point is that the items in this set are interconnected by the ability of such professionals to recognize and represent problems and intervene in the world - based on their knowledge base and the available technologies - with a view to finding and applying/managing solutions to them. But this discussion is not far from the problem regarding assumed values, in other words, the professional's ethical behavior. What are problems, how should their consequences be considered and accepted or managed, how should limitations be accepted on account of the possible impacts? Only a solid ethical formation that permeates this entire logical body will be capable of answering this question. But this a topic to be discussed in another paper.

THE ENGINEERING CURRICULUM

The formation of the engineer portrayed above leads to the teaching methodologies associated with *Problem Driven Education* [6]. From the very beginning, engineering education must be based on problems in order that representations and different ways to solve them may be attempted, but the tools for representing and analyzing the natural and social phenomena that compose the problems must not be disregarded - the necessary scientific education, and its application at the service of problem-solving in engineering. This is what presents one of the major challenges to the pedagogy of today: the need to interrupt the sequential order of presentation in such a way as to make sense of the theories and representations while promoting the development of an enterprising and ethical attitude as well as of managerial capabilities, including self-management. If we expect future engineers to be able to anticipate problems and strategically organize their solutions, we are

forced to acknowledge the importance of a cross-disciplinary educational model that is not in conflict with, but rather supplements the specialization models qualified as specific graduate courses by approaching the teaching of engineering and the existing forms of accreditation in a complex manner.

These considerations lead to a curricular structure and a university structure (the manner in which the engineering course is inserted in the research university) that differ from the usual ones, as has been predicted and explored in Gibbons[7] (n.d.) and Aranha et al. (1998)[8].

The research that has been carried out and the model that is now being introduced turn one's attention to the historical evolution of the educational model, from the scholarly medieval vision to an attitude of ultra-specialization (20th Century), to today, when the need has arisen to generalize education once more in a very particular way. This particularity is characterized by a generalization of the technological and scientific bases (that include biology as well), which is articulated with conceptual structures that are committed to the challenges established by globalization and by the regional foci that are being developed (e.g., the European Community and the F.T.A.A. prospect). The logical body must be organized in such a way as to make it possible to read reality in advance, represent it symbolically, model it and construct optimized solutions; it must be characterized by competencies related to management, entrepreneurship and administrative flexibility in order to cope with the constant changes in global scenarios with the necessary speed, and it must ethically address the social, professional and environmental aspects, which are to be viewed as regulatory elements for the solutions that have been elaborated. It is no longer possible refrain from extending the logical body towards the new fields of study and education (social studies, managerial attitudes, for example) and to the formation of poly-specialized engineers. However, as stated in the analysis in da Silveira et al. (1999), the old generalist and scholarly studies are not desirable, but in-depth poly-specialization is not possible (educational time is finite). For this reason, the logical body that has been indicated here requires a new structure for schools and their pedagogical practices, a structure that must address the engineering problem and the quest for its solutions within an environment that is interconnected with the socially immersed professional world - without disregarding the momentum that an open and multidisciplinary scientific and cultural education transmits.

CONCLUSIONS AND RECOMMENDATIONS

The research and the conceptual formulations that have been carried out have identified, in the process of characterizing highly mobile professional engineers - that have come to be known as Engineers of the Americas, the importance of introducing a professional that is capable of managing highly complex projects in a manner that complements the work performed by traditional "technicist" engineers, that is committed to the social and environmental aspects that regulate his/her actions, and that is flexible when dealing with the uncertainties and volatility of the structures that support the social and economic relations of the modern world.

It should be pointed out that the profile that has been proposed here is by no means intended as a suggestion that engineering education should be standardized. Instead, it introduces one more option within the set of possible profiles for these professionals. Consequently, as the research that was performed has pointed out and the example of the French engineering schools has demonstrated, it is up to the university institutions to carry out their strategic options by defining their educational profiles, based on which they will act and organize their formal structures and their teaching methodology. Different schools with different educational profiles will produce professionals that range from engineers that are responsible for the shop floor to those who are responsible for a company's strategic management.

It is especially recommended that a special working committee analyze and propose, within the theme related to engineering education and accreditation, the different levels that this logical body must have in order to meet the demands associated with the mobility and the professional competence that an engineering graduate needs.

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