Trends in engineering education - Programs' content, implementation to meet current challenges

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Abstract—Many engineering issues cannot be addressed without profound knowledge of social and political dimensions, such as; energy supply, drinking water and preservation, mitigation of air and soil pollution, climate change, use of biotechnological potential in agronomy, food and medicine, closely interact with society, public sector and environment. Indeed, these topics are so complex that they must be treated by multidisciplinary teams with qualified members and where, each member is aware of concepts and approaches of others, while knowing that globalization produces major societal challenges with impacts flowing between and through borders in ways, we were unable to predict or expect. Also, engineering careers became more and more, entrepreneurial and global, while technological change pace has accelerated and expectations regarding engineering education have widened. Additionally, we know that scholarly and methodical improvement of engineering education are based on a continuous cycle of educational practice and research that constantly, advances the body of knowledge on engineering learning, leading to the implementation of more effective and reliable educational enhancement with a final result of better educated students. Far from being exhaustive, this paper presents some issues and tendencies for the program's content in engineering education.

Keywords— Engineering education challenges; Interdisciplinary engineering education; Professional skills; Programs.

I. INTRODUCTION

Considerable progress has been made towards improving the well-being during the previous decades, without regard to the environmental preservation, thus leading to risk taking, which in some cases, appears to have generated our future challenges for the next century. In fact, the signals are ubiquitous that our planet is experiencing major climate change and it is clear that we need to reduce the emissions of carbon dioxide and other greenhouse gases from our atmosphere if we want to avoid greatly increased risk of damage from climate change. Resolutely pursuing a program of emissions abatement or mitigation will show results over a timescale of many decades. In addition to other examples that abound as; energy supply, conversion and storage, clean water and water conservation, mitigation of air pollution, land and water, health care for disadvantaged people by global warming, and use of the potential of biotechnology to agriculture, food and drugs. It appears that some of those issues have contributed to the current state of the climate. Many engineering issues cannot be solved without a deep knowledge of social and political dimensions, and in the knowledge that real engineering challenges are increasingly multidimensional and not just technique [1].

What should be done to meet these challenges? To make decisions will require a team of scientists and skilled engineers and a scientifically literate public. University professors, university and political leaders also play critical role. The political leaders in taking appropriate political decisions and university officials to implement resolutions and thus enhance the quality of training, in preparing students whether as professionals in engineering and science or as informed citizens to meet the challenges through their various contributions. Indeed, these issues are so complex that they must be treated by multidisciplinary teams with qualified members and where every member is aware of other concepts and approaches, knowing that globalization produces major societal challenges with effects flowing between and across many borders in ways that are difficult to predict or anticipate. So, engineering careers have become increasingly entrepreneurial and global, so that technological change has accelerated the pace and expectations regarding engineering education have widened [1].

In addition, an education system is closely linked to scientific, technological and economic environment in which it evolves. Before examining new approaches to train engineers, we first need to start by anticipating some features of the society in which we form engineers and where they could work and achieve their accomplishment. In society's economy, added value mainly grows due to the application of knowledge and based technologies on innovation. Consequently, these are the society's requirements towards universities as "knowledge producers" that are and always were subject to change [2].

Also, several national and international organizations have either adopted strategies after identifying issues, as with the National Academy of Engineering NAE (USA) [3] or proposed new concepts and paradigms with different regulations / recommendations that should be considered by all countries as is the case for the United Nations. The UN recommendations for the main challenges identified, that concern the entire educational system, including engineering education for engineers training, who are in fact technologies creators [4].

Long before, the Accreditation Board for Engineering and Technology (ABET) [5], proposed to hold engineering schools accountable for the knowledge, skills and professional values engineering that students acquire (or fail to acquire) in the course of their education. Since 2001, Engineering Criteria 2000 were implemented as the standard for accreditation. Thereafter, all U.S. engineering departments had to demonstrate that besides having depth knowledge of science, mathematics and engineering fundamentals, their graduates possess communication, multidisciplinary teamwork, and lifelong learning skills and awareness of social and ethical considerations associated with the engineering profession.

How would we address such issues? Prioritizing the qualities of engineer that we would like to have: with skills, etc., which kinds of courses and percentage in their hourly volume; which percentage of the fundamental and technical sciences and practical works, likewise for the cross-cutting disciplines, as; human sciences as sociology, etc., and sustainability, engineering ethics, disaster mitigation, risk management. All of them contribute to solving the cross-cutting issues as energy, materials, nanotechnology, sustainability, biological and chemical treatment, safety and security. Which kind of training? By research or not? This is according to students' number, program structure and even to the responsible of institution of the education, etc.

The critical questions to answer for meeting these challenges may require continual curricula review, but not only. In fact, the changes that will lead engineering education in desired directions could be outlined into two kinds: (a) revisions in the engineering curriculum and course structures, with implementation of new teaching methods that could provide more interactive classes; (b) establishment of educational development programs for faculty members and graduate students, accompanied by the adoption of measures to raise the status of teaching in society and in hiring institutions, advancement, and reward policies. But this depends on suitable governance enabling the institutional governance to evolve, so allowing a periodical refreshment of managers and educational and scientific activities compatible with the scientific and technological advances.

II. Technological Quality and skills Of The Future Engineer

Gaps in engineering education have been identified and discussed in recent years. The engineering universities/ schools and professors know that they should strengthen the coverage of fundamentals; teach more about "real-world" engineering design and operations, including quality management; cover more material in frontier areas of engineering; offer more and better instruction in both oral and written communication skills and teamwork skills; provide training in critical and creative thinking skills and problem-solving methods, in order to produce graduates who are aware of engineering ethics and the connections between technology and society [6].

We quote also, that currently and for the coming decades, many salient features will be a challenge for future engineers among them: *Spread of documents and information*, in fact, the number of documents available is growing rapidly with an accelerated pace and will continue. Furthermore, the information stream is beneath the fingers of engineer through internet, virtual environments which can each contain up more than one million pages of text. Also, *technological development* requires a multidisciplinary approach [2]. If at the start of the century, the practice of engineering was classified by the disciplinary criteria insofar as university programs were, what was the body of knowledge of the studies like chemical engineering was well defined and distinct from that which characterizes mechanical or electrical engineer or a chemist or physicist. The situation is now more complex: for example, any types of engineers are faced with a need to know their discipline as well as biochemistry electronics, etc. The key to a better *technological development* lies in the collaboration between the disciplines previously separated to address problems that have no recognizable disciplinary boundaries. Also, due to globalization, industries which cannot compete in *the international market* are unlikely to survive in the *domestic market* and succeeding internationally requires cultural and economical understanding at least not less that the technological expertise.

Given the rapid development of technologies, everything that needed to take a year, there is not so long, it occurs today on the scale of months, weeks, days or less. For programs that need to be updated with the industry practice by providing permanent courses in the "new technology" may be somewhat inefficient. Indeed, when the need is identified and courses developed and students trained, the new technology has changed. However, *lifetime learning* will be the one to succeed facilitating this type of learning and skill's students will need *to adapt to change*. Moreover, concerning the *protection of Environment*, the paradigm according to which "produce more to earn more" will not be exclusive to the industry. Indeed, threats on quality of life resulting from environmental depredations sprees and the depletion of non-renewable resources are a source of growing concern even within industry. In addition to the quality and productivity of the industry, profitability would have to be reached without affecting people. Increasingly, industries are adopting the process of," *green approach*" to guide their decision making on the use of the planet's resources.

We remark that all countries unfortunately are not equal in terms of training, if for some these are only some adjustments to be made for other reforms need to be considered due to human and financial unavailability.

Furthermore, the gap widened between technologically advanced societies and those lacking basic means to survive. Although the origins of most of these problems could be more political than technological, it is important for scientists and engineers to participate in decision making, with greater strength. They have obligations to themselves and the rest of the population on potentially social consequences of the decisions taken. The acceptance of this *social responsibility* by industry and engineers represents a necessary step to ensure sustainability of society.

After the enumeration of the circumstances for which certain qualities are required for a professional engineer, we can summarize them as follows [6]; The competent graduate has to be independent and interdependent with skills like lifelong learning, solving problems with a critical and creative thinking. He must be interdependent and agree teamwork and have written and oral communication skills and competence of the self-evaluation. All of these skills must be complemented by integrative and global thinking with change management skills.

Due to complexity and the number of skills' settings to consider, the issues of engineering education (outlined above) increased with the needs for more diversified and professional engineers. This means that the improvement of the learning process and evaluation of cross disciplinary professional skills have become even more important than before. Engineers are expected to have multidisciplinary knowledge [7].

We could say that the engineer profile could be easily outlined in terms of his knowledge; the skills he uses in managing and applying his knowledge, such as computation, experimentation, analysis, synthesis/design, evaluation, communication, leadership, teamwork and finally attitudes that dictate the goals toward which his skills and knowledge will be directed. In fact, knowledge is the database of a professional engineer and skills are the tools used to manipulate the knowledge in order to meet a goal dictated or strongly influenced by the attitudes [2].

III. Engineering Education - Curricula And Courses

The new engineer's profile would be aligned with what we shall call, “knowledge, green and sustainable economy," where even the business community should evolve from simply “meets the requirements of a product to finding more complete solutions.” The profession has become more multidisciplinary and global, and requires general management skills. Beyond the training core such as basic scientific and technical skills, the engineers need to develop skills associated with project management, green economy, sustainability, risk management, systems engineering, global marketing, interpersonal relations, foreign languages, communications, etc. The best engineer is the one who can organize, work in a multidisciplinary and multicultural business and think locally and globally. For that purpose, worldwide engineer's communities are seeking ways to put knowledge into practice to meet these grand challenges. The impressive number of done works about this subject gives an idea on the academic industrial world concern [8].

Engineering covers a broad and diverse areas, fields, disciplines or specialties, whose number increases with the technology evolution and the emergence of new branches of engineering is continuous. We can mention more than twenty-five; among them civil, mechanical, chemical, electrical and electronic engineering, etc., developed with differentiated knowledge [4]. The curriculum should be;

- *Interdisciplinary***.** Preparing engineering students to work at the overlap with public policy, business, law, ethics, human behavior, risk as well as medicine and the sciences. Examples that span these disciplines with a coherent theme are Energy and the Environment, Sustainability, Uncertainty and Optimization, etc.
- *Entrepreneurship***.** Preparing students to translate invention to innovation; to develop market ventures that scale to global solutions in the public interest.
- *With global dimension***.** Developing the students’ global perspective necessary to address challenges that are inherently global as well as to lead innovation in a global economy.
- *Service learning.* Developing and deepening students’ social consciousness and their motivation to bring their technical expertise to bear on societal problems. Programs such as Engineers without Borders, or Engineering World Health could be adapted to meet this component.

A. Some raised questions related to the content of the undergraduate program

In view of the many skills and competencies required for engineers and the number of courses to be taught theoretically and practically, there are relevant questions that are typically raised during the elaboration of a given program. Among them, we mention those related to the structure of the program as follow [2];

Considering many skills and competencies for engineers and the number of courses that will be taught theoretically and practically, there are relevant questions which are typically raised during the elaboration of a given program. Among them;

- What is the proper balance between the sciences and the applications basic? Individual courses should focus on one or the other, or both integrated in the courses? How and where the flow in a course or curriculum generally move from

fundamental to applications (deductive presentation, conferences) or from applications to the fundamentals (inductive presentation, discovery learning, Problem-Based Learning)?

- What measures can be taken to integrate classroom materials through courses and disciplines so that engineering students get used to think in interdisciplinary criteria in their approach to solve problems? How may the set of concepts be presented systematically throughout program?

If we consider all the skills that graduate should acquire during his training.

- How can we accommodate the various teachings of sciences, engineering basic and those of social and human sciences that are interdisciplinary?
- How should the development of critical skills, those outlined above? How much should be done within core engineering courses and how much should be relegated to specialized courses such as courses of communication and ethics?

B. The others complementary skills to meet the challenges of the coming century

As we know, engineering program can be expressed in terms of two main aspects: the "knowledge" and "skills". Skills can be divided into those that are specific to the type of program, and those that are "generic" or "transferable" (e.g., "problem solving"). Many studies on transferable skills can be found in the literature [9]. However, from a range of sources, there is a great agreement for the main skills that are reported in Table 1.

TABLE 1: DEFINITION OF TRANSFERABLE SKILLS

Transferable skills			
ABET 2004	**IChemE E 2001**	**AGR 2003**	**(GCCA 2004**
Teamwork Solve problems Communicate Lifelong learning	Communications Teamwork Time Management Inter-personal Lifelong learning	Motivation Teamwork Numeracy Communication Solve problems (proactively) Flexibility	Communicate Inter-personal relationships Embrace change Lifelong learning

Since the new engineers should have a wider set of attributes, in addition to scientific and technical knowledge, it depends on the capacity of the institution of engineering to make or not a change, such as filling gaps in knowledge and skills by giving some extra weight or adding them as new courses in engineering programs, which can be advantageous. Two ways to introduce them into the curriculum, integrated or as separated courses. *Sustainability, safety and risk management* security, and risk management, sustainability, *Engineering ethics education* and professional responsibilities that are somewhat neglected in the southern universities for many reasons.

Sustainability, safety and risk management: Climate change is our major challenge of this era, economically, scientifically and technologically. Meeting this challenge provides the greatest challenge and the greatest opportunity that engineering profession has ever faced. The challenge for engineers of the future is to better understand the science, engineering and design vital issues with a comprehensive understanding of how national economies will make the transition to future low gas emissions. Given the rapid growth of greenhouse gas emissions globally there is a real need for a greater level of urgency and sophistication around the realities of delivering cost effective strategies for policies and engineering designs to achieve emissions stabilization globally.

In addition, several major disasters worldwide in many industries; petrochemical; heavy and fine chemistries; food and pharmaceutical had led experts and industrials to recommend to universities to teach all parts of environment protection with *safety, risk management* and to professional bodies to introduce an obligation that *safety* and loss prevention *be part of the academic curriculum*. A lot of points of views can be found in the literature related to safety from its integration as a part of the design of plants to special courses. Aiming a safe design, the safety process must be taught in a rigorous and stimulating way by staff of appropriate experience. *Sustainability* will be the context within which all engineering kind will practice throughout the 21st Century and beyond. A renewed curriculum and recalibration of engineering graduates' perception of their roles and responsibilities towards society will help swift the societal paradigm change that will occur as a result of the consequences of a global society engaged in continued unsustainable practices. It is the ethical responsibility of engineers, to lead on altering the attitudes of society, given the unique position of engineers, in understanding and applying systems approaches and due to their capacity to design and develop the products and processes that will help realize a sustainable society [10].

Engineering ethics education; Teaching engineering ethics could achieve some desirable outcomes as the increasing of: ethical sensitivity; knowledge of relevant standards of conduct; ethical judgment; and ethical determination (that is, a greater ability to act ethically when one wants to). The objective is to sensitize the young students with the ethical aspects of their studies and to prepare them to their future profession.

IV. Conclusion

Nowadays the society's evolution is substantially determined by the quality of education. A special role in this respect is played by universities whose mission is to educate the decision-makers in all social spheres. However, many universities in different countries are experiencing a grave crisis, some the growing large number of students with Academic staff lacking with a real management issue, for others the finance or students are lacking etc.

National economies and civic participation depend more than ever on the presence of a community of properly literate and educated citizenry: this means that the global educational community must respond to multiple and serious challenges. Only with an informed, literate and active citizenry we can meet the challenges of our society effectively – and this can only happen by making adult learning and education the focus of policy and action, as a transversal agenda that cross-cuts policy domains and resource allocations.

A recurring theme for those interested in engineering education is that the complex challenges of the coming century will require more creative, innovative, and holistic solutions. Maybe that engineering education needs new ways to train engineers. In reality, in the developed and emerging countries and more or less in the developing world, reforms were undertaken, both to restructure the architecture of training in general and engineering, in particular, in order to prepare future generations for the challenges of the 21st century. However, this is a big challenge, where we continuously have to reconsider the training [3]. The original and innovative way to make change possible, depends on active community of practitioners and researchers working together to advance knowledge and practice.

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Biography

Khedidja Allia is a Chemical Engineering Professor and research director at the University of Sciences and Technology (USTHB), Algiers. She holds engineer diploma and Doctorate Es Science in Chemical Engineering at National Polytechnic School, Algiers (ENP) and part at Thames Polytechnic – London-UK. She is engaged in the supervision of students at diff²erent levels (Doctorates, Magisters, masters), and lectured at the USTHB (Algiers) and she is member of Scientific committee of the faculty. She published several scientific works in chemical and environmental engineering field (Multiphase flow, Pneumatic conveying, fluidization and wastewater treatment, solid wastes…..), and is involved with number of research projects and was Fulbright Researcher at Cornell University, Ithaca, USA. She occupied several posts as; Director of Higher Education (MESRS), Director of ICI-USTHB and President of Scientific Committee – ICI, Head of Chemical Engineering Department at the National Polytechnic school, and Researcher at SONATRACH. She took part at many commissions on the higher education reforms, and she was the National Coordinator of « the higher education Commission (Technology) of "Maghreb Equivalence", and president of PURAQ (Pôle Universitaire et de recherché Algéro-Québécois). For her achievements, she has been awarded and appreciated by State and Global Institutions.