Engineering Education in the K-12 curriculum

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Abstract- **Educators and parents have long accepted, as obvious, the fact that students who perform well in mathematics and physics are the best candidates for becoming future engineering students. While in fact a good number of these students do not succeed in engineering studies, and some of them end up doing something else in their professional life.**

This paper tries to prove that in the K-12 curriculum students are not prepared to the concepts that underlie the engineering programs. On the other hand, the paper will try to prove that some basic concepts may be introduced in the curriculum from a very early stage to enhance not only the scientific knowledge but also other high mental skills needed for engineering studies, and other technical competencies. To illustrate its statements the paper will use as case study the Lebanese Curriculum adopted in 1996.

The paper will build on the conceptualization theory, mainly the Conceptual Fields approach, to illustrate how such integration may be achieved by adopting a constructive and practical driven approach to introduce and master the cross disciplinary knowledge needed in engineering studies. Such an approach will have its impact not only on the curriculum content but also on the teaching and learning strategies to be implemented within the K-12 educational system.

NEW NEEDS FOR A NEW ERA

In its *Millennium Project*, the University of Michigan published a document titled *Engineering for a Changing World* that aims to be "a road map to the future of Engineering practice, research and education" [2]. This document tries to sum up a number of studies related to Engineering Education that try to respond to the new needs appearing all over the world and challenging the schools of Engineering. Researchers in Engineering Education, as well as those in Sociology, Psychology, and Behavioral Sciences, are taking seriously the challenges raised by a new era where professionals are facing problems for which they were not prepared.

In addition to their global impact, these challenges are questioning issues related not only to the engineering curriculum content, but also to its learning methodologies and evaluation procedures, to its relation to other fields of knowledge, and finally to its aptitude in forming personalities able to adapt to our fast changing world.

THE CONTINUOUS CHAIN OF KNOWLEDGE

On the other hand, new approaches in Science Education make it clear that the chain of knowledge is a continuous one, and that information gathered monolithically and disruptively is a poor resource for efficient future impact. This difference between information dissemination and knowledge mastering is basically what may differentiate in the future an application driven technician from a problem solving driven practitioner.

The *Conceptual Fields* theory [3] is very helpful in incorporating the two main features of modern education: i) the knowledge, continuity, and evolvement in a specific discipline and ii) the cross disciplinary aspect of knowledge acquisition. This theory, by offering to educators the possibility of adopting a holistic approach which links the market's needs to the ways of preparing practitioners from an early stage, to perform as flexible and communicative actors of the society, may be the best way to introduce the needed changes.

THE IMPORTANCE OF THE K-12 CURRICULUM

One of the main features of this theory, based equally on Cognitive Psychology and on Constructivism, is the emphasis it puts on considering that the different stages of knowledge building and mastering to be a continuum. Even if the flow of new information never stops, the way such information is integrated to enrich existing personal knowledge, is an important aspect of success.

The Cognitive Psychology, based mainly on the works of Vergnaud [6], builds on the fact that a concept is a dynamic entity that operates in specific situations, using specific schemes, invariables and symbols. On the other hand, mastering a concept means the possibility of using it genuinely and creatively under new conditions, and this is only possible when this comes as a result of progressive and continuous introduction of the concept's components as pre-concept rather than as concept-in-act.

At the same time, adopting the constructivist approach means that such introduction is done taking into consideration the different developmental aspects of the learner in terms of language acquisition, mastering of high mental skills and accumulation based information. The role of the education system is to manage the needed harmony in introducing and implementing the processes of such strategy.

The importance of the K-12 curriculum is its being the basis of and the source for any future development of skills related to higher education. By minimizing the role of the K-12 formation, educators in fact are minimizing any further education by taking for granted the discontinuity in knowledge building and by reducing any higher education formation to its specific technical material (skills and content).

THE ARTICLE'S STATEMENT

This article assumes the following: Rooting Engineering Education in the K-12 curriculum is doable and will help in enhancing a new approach to Engineering Education mainly in stressing the importance of the non conventional components of such education.

To support this statement, we will try to see how such new trends in Engineering Education are closely related to the main features of a good K-12 curriculum. We will emphasize the aspects defined by the ABET's Engineering Criteria, or foreseen by the TMP document [2].

THE LIBERAL ARTS COMPONENT

"To establish engineering as a true liberal arts discipline, similar to the natural sciences, social sciences, and humanities, by imbedding it in the general education requirements of a college graduate for an increasing technology-driven and –dependent society of the century ahead." [2]. Considering that Engineering was and is still perceived as an applied science discipline, this claim seems to be a revolutionary one. In fact, performing as engineer in the 21st century context asks for different types of skills that go beyond the technical aspects of the curriculum. At the same time, technological outputs offer to mankind tools that are merely the direct products of engineering processes. This friendly aspect does not appear while dealing with Engineering as science or as profession. Stressing this *liberal art* aspect is of utmost importance because it leads to the rediscovery of the Engineering's human dimension as an approach to development.

This *liberal arts component* may be easily rooted in the K-12 curriculum and will create an adequate atmosphere to deal with engineering issues as part of a broad human context. To illustrate such possibility, one can gives some examples taken from different levels of the K-12 curriculum. Here are few of them:

A. The engineering aspect of the famous buildings mentioned in the history of arts as a human heritage, as early as grades one or two.
B. The engineering role in going from theoretical mathematics or physics to technology and its outputs, mainly in grades 10 to 12.
C. Engineering as part of the Civilization evolvement through ages, especially in the intermediate grades.

This liberal arts aspect of engineering that stresses the friendly approach to the profession in the K-12 curriculum, will help introducing this aspect into the university curricula, and will give new horizons to the way new generations will look at this profession and deal with its outputs.

THE COMMUNICATIVE COMPONENT

Speaking about Engineering Education, Bordogna [1] considers the following items as an integral part of this educational process: i) language and multicultural understanding, ii) ability to advocate and influence, and iii) team working. It is obvious that such criteria are not introduced at the college level and they are called to be part of the pre-college education. By stressing the scientific aspect of Engineering as a discipline, we forget how much it is important to be at the same time open minded and communicative in order to be permeable to the needs of the society on one hand and to convey the technological message on the other.

While it is perhaps difficult to allow enough time in the college for this aspect, a K-12 curriculum, by being aware of the importance of these communicative skills, is able to give room to new ways of expression and to new subject matters related to real life situations. New tools of communication through multimedia and new technologies are available now and can be used at an early stage and can be heavily introduced in pre-college education. This will be a tremendous help for universities to receive students already familiar with these tools and able to use them for communication as part of their language potential. This will need a new look to the K-12 curriculum to merge language skills and new techniques of communication along with team work, group debates, presentations etc.

THE HIGH MENTAL SKILLS COMPONENT

It is universally admitted that mastering High Mental Skills is a must in university education. While some of the university curricula do not stress this aspect at the undergraduate level, they become indispensable at the graduate one. In many countries, Engineering is looked at as a 5 year degree and as such requires the mastering of such skills.

Looking at the actual status of such curricula, one can see that there is no systematic way to ensure that such acquisition has been done, and even at the undergraduate level, curricula do not mention the introduction of Critical Thinking or Scientific Methods as part of their requirements. A valid question that some educators raise is the following: Do we have to wait for the college level to make such introduction? Some other go further by saying that it will be too late then! Making the acquisition of High Mental Skills one of the main objectives of a K-12 curriculum is doable, helpful for the learners at all stages, and valuable at the college level.

Making this integration is a process to be implemented gradually starting with the first school grades. Empirical researches [4] show that such a process has an immediate impact on the learners' abilities, and will enhance their future performances. This is true across all university majors and not only Engineering.

THE SCIENTIFIC COMPONENT

Usually, outsiders stress the scientific (mainly Mathematics, Physics and Chemistry) component of the Engineering curriculum and consider this component as the main feature of the degree. While this aspect can be considered as predominant at the theoretical level, it is far from being the main feature of the discipline. Looking at the requirements stated in [2] it is clear that addressing other requirements for being an Engineer is more challenging and more demanding.

The scientific theoretical background is a must, but it is not an objective by itself. It has to be looked upon as a tool for developing the abilities of an Engineer in solving new problems with creativity and acuity. Here comes the importance of the Conceptual Fields Theory that gives a new approach to curriculum building and to the learning strategies. But this gives also an idea of how this vision of the scientific component can be built up in the K-12 curriculum.

From an early stage, introducing the scientific concepts can be done through a problem solving methodology, which is to become the heart the Engineering profession. Adapting human mind to such a methodology inherent to the engineer's professional life can be realized by a new look to teaching Maths and Sciences. Demystifying sciences will go forward with new learning strategies that will grow gradually.

For the time being Sciences focus on the descriptive aspects of objects, while Mathematics focus on calculation and direct applications of the theory. Rarely merging between both in contextual situations is the source for problem solving leading to conceptualization. The backfire of the actual status is affecting the way learners look at Maths and Sciences, and the way they are prepared for Engineering Education.

THE CROSS DISCIPLINARY APPROACH

At the same time, and as a result of the narrow vision of Engineering Education, all other aspects of the university education are minimized. But, nowadays, engineers perform in a totally new environment. They are global professionals, working in a movable human, social, and cultural environment. Apart from the linguistic and communicative aspect, engineers are challenged by new opportunities for work and they are asked to adapt themselves to changing conditions which requires from them an open mind approach, a good knowledge of global work conditions and cultural awareness.

This cultural openness cannot be reached during the college years. It is an attitude that has to be adopted as part of personality building. Teaching History, Geography, Economy, and Civilization is not a luxury in a K-12 curriculum. It is part of a realistic outlook at our world today. Engineers are the professionals who move the most in the global market today. Considering this cross disciplinary aspect as a prerequisite to Engineering Education may be helpful for the future of the profession. This is a domain where the pre-college education may offer a lot.

THE LEBANESE CASE

As an example, we are going to take the Lebanese Educational System as a case study. Lebanon has an advanced Higher Education System that goes back to the 19^{th} Century, with 7 schools of Engineering from which an average of 750 students graduate each year. The majority (around 80%) of these graduates are recruited by the industry, mainly in the Arab World, while others go on to graduate and postgraduate studies in North America and Europe. These schools have different curricula and adopt different approaches to Engineering Education, based mainly on the French and American models. Nevertheless, the similarity among them is large enough, to justify classifying all these programs as *classical* ones.

On the other hand, Lebanon has adopted in 1996 a new K-12 National Curriculum which intended to prepare learners to cope with the needs of an open and changing world, and focusing its methodology on the learners, while trying at the same time, to ensure a better continuity within the whole educational system of Lebanon [7]. This is why considering the Lebanese case will be interesting for the purpose of this study.

In 2000 the UNESCO commissioned the Lebanese Association for Educational Studies (LAES), to audit the new K-12 curriculum, based on a national wide empirical study and covering all the features of the curriculum and its implementation. This study was executed in two stages and its results were made available to the public between 2002 and 2004. This case study will build on the findings of this evaluation.

a- The curriculum objectives

The new Lebanese Curriculum emphasized, in its general objectives, the importance of linking disciplines to real life situations [9] and calling for the adoption of new learning strategies. But at the same time the process adopted in developing the detailed objectives of the different disciplines and grades missed following up on the concept and on establishing such links. At a later stage, the books that were edited according to the curriculum, failed in filling this gap, and young learners still, are not exposed to look at their future professions as a way to incorporate knowledge as part of their daily life and as a vehicle for social and personal development.

This is clear when one looks at the way teaching of Maths and Sciences is approached. For example, they are being considered apart from the teaching of Technology. Using computer skills is considered independently from any exploitation in other disciplines. Teaching techniques are still driven by an instructor centered methodology.

b- The communicative tools

One of the main impacts [9] of this discrepancy between the general and the detailed objectives is to be found on the Language and Communicative components of the new curriculum. Students coming from the K-12 Lebanese curriculum face serious difficulties in acquiring efficient communicative skills at the university. Those who choose to enroll in an engineering program do not consider that such acquisition is indispensable to their future performance as engineers. The 21st century engineers will work in a global and multicultural environment but Lebanese students, even if they are aware of this encounter, are not prepared for it.

c- The High Mental Skills

The new curriculum was based strategically on a document calling for renewing the whole system [7]. This document, adopted by the Lebanese Parliament, specifies that the main vision of the educational system is to *produce* citizens with critical thinking potentials, able to adopt scientific strategies and methodologies while dealing with national issues.

The curriculum and its implementation phases fail to say how and when learners will be introduced to these skills and how instructors and educators will be able to judge the mastery of such skills. On the other hand, the curriculum contents of the different disciplines did not mention how and when such skills will be efficiently used.

This is where the problem lies. How do we move in a K-12 curriculum from a wishful thinking status to an efficient implementation phase? How do we audit the results of such issues? While everybody agrees on the importance of the acquisition of High Mental Skills, we were not able in Lebanon to implement adequate learning strategies for that. Not only is the Engineering Education in Lebanon suffering from this deficiency, but so is the whole University system.

Conclusion

It seems that a new era in Engineering Education has started with this Century. The profession is approached with new paradigms. Engineering Education does not look anymore at the engineer by trying to say who he is, but by emphasizing what he will be able to do. In its *Subject benchmark statement* for engineers, the Quality Assurance Agency for Higher Education stated [5], that engineers would be challenged through their “way of thinking”. At the same time in its chapter 6, the *Engineering for a changing world* [2] tries to propose a roadmap for the 21st Century Engineering, specifying where the changes are needed and proposing practical steps to reach the objectives.

But at the same time, and because of the educational continuum, this new benchmarking of the Engineering Education needs a change of mentality towards the profession and a cognitive preparation that must start in the pre-college stages. In both cases a new look at the K-12 Curriculum becomes a must. With the evolution of new technologies, Engineering seems to be the most challenged profession today and hence is the one that is mostly in need of a new approach to the K-12 Curriculum. This is what we have tried to prove.

Finally, the Lebanese case shows us that the existence of a vision, even on a national level, is not sufficient. All the actors in the Education System have to be aware of these new needs, have to adopt drastic changes, and have to act accordingly: decision makers, educators, administrators etc. These changes are profound and will be implemented only through strategic decisions related to Education. The evolution of Cognitive Psychology, Education theories, and Didactical approach to learning/teaching techniques, will be very helpful in preparing the ground to adopt such new strategies.

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