A View on Electrical & Computer Engineering Education :
Challenges toward Convergence of different Disciplines

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1. INTRODUCTION

It is well established that the duration of engineering education requires at least five years in order to establish the required background for handling both practical problems as well as to be ready for a research carrier. The political elite in Europe in collaboration with the industry has adopted the Anglo-Saxons' model of the split three years Bachelor degree and one two years Master degree. However, the Academic community in full agreement with the Engineers Professional organizations seems convinced that the best Engineering education should be based on an integral five years curriculum, considering the adopted model as leading to dispensable young Scientists. The weakness of this latter thesis is that most five years Engineering undergraduate programmes include at least one year (usually three semesters) of specialization. One could claim that this makes the curricula somehow split into two circles, hence similar to the accepted Bachelor-Master approach. The argument against this view is that the "integral five years" path can be setup in a more controllable way so that the specialization is build on rigid bases. To these different point of views must one should add the recently realized necessity of the required "Convergence of Engineering, Physical and Health Sciences" in order for engineers to advance the technology beyond the current borders and especially regarding novel diagnostic – therapeutic techniques and health services, [1]. Besides that it is now a common understanding that a modern engineer must establish a rigid theoretical background and not just a restricted knowledge specialization, so that he/she will be able to adapt to the fast varying of technical environment with a high rate of newly introduced plethora of specializations.

In view of the above, the question is whether the newly reformed Electrical & Computer Engineering in Greece are able to successively respond to these challenges. If they can't what are the reasons, is it possible to overcome the obstacles and how? If we do accept that a rigid theoretical background is necessary, what will be the content of the corresponding mandatory

curriculum? If we do agree that "an integral five years engineering education" is needed, what are the means to be used for convincing the political elite and the industry representatives?
The above questions constitute a serious problems and they cannot be addressed in a single paper. The intend of the Author is to systematically put down the questions in some logical order and the ambition is directed toward addressing some of them from his own point of view and experience.

2. A CRITICAL REVIEW OF THE CURRENT ELECTRICAL & COMPUTER ENGINEERING CURRICULUM

The current undergraduate electrical & computer engineering curriculum in Greece mainly consists of a core of courses taught in the first six semesters, with six mandatory and one elective course per semester. With the beginning of the 7th semester students are asked to choose a specialization from power, electronics and microelectronics, telecommunications and software engineering which is comprised by three semesters of courses and the last (10th) one is devoted to the diploma thesis.

The National technical University of Athens (NTUA) has additionally adopted a number of 14 flows within the four specializations as:
1) Computer Systems, 2) Software, 3) Electronic Circuits & materials, 4) Communication & Computer networks 5) Waves & communication signals 6) Control & Robotics, 7) Electromechanical energy conversion – high voltage and installations, 8) Electrical power systems, 9) Management & Decisions, 10) Bioengineering, 11) Physics, 12) Mathematics, 13) Courses not included in flows and 14) Humanitarian courses. According to NTUA Undergraduate guide [16], the requirements for an engineering diploma award is successfully pass 60 courses and the diploma thesis. The 35 courses belong to the core programme (5 semesters instead of 6), while the remaining 25 must be from either 3 complete flows (7 courses/flow) or 2 complete and 2 half flows plus 4 free courses. Besides, at least 18 courses should belong to flows 1 to 8, which are more technically – engineering oriented.

In contrary to the NTUA flows – system the other 3 electrical & computer engineering departments (EECE, Thessaloniki, Patras, Thrace) have a specialization curriculum with different group of courses with very few common courses. Students are allowed to receive as electives 1 to 2 courses per semester from the pool of the other specialization mandatory courses. However, in practice this is very difficult due to restrictions in lecture room's availability and in scheduling the lecture hours of too many courses.

The detailed description of NTUA's flows system herein has a specific meaning, since it can efficiently support the intra – disciplinary convergence (smart power grids, software – defined and cognitive radio SDR-CR) rising in our days. Besides the above, going through the "self – validation reports" of all Greek EECE departments one may realize some important observations.
1st) very low motivation of students during the first 3 to 4 semesters revealed by low attendance into course lectures and very low average grades. Actually, the first semester's lectures start with very high student attendance, which is gradually diminished. The situation becomes worse during the 2nd and 3rd and starts improving after the 5th semester.
2nd) Student attendance and consequently their average grades are impressively improved during the specialization semesters, mainly due to their high motivation. 3rd) Students achieve their best performance during the 10th semester when they work for their diploma thesis.

A factor contributing to the students' low motivation during the first semesters is the primarily theoretical nature of the courses and the restricted access to laboratory exercises. Conversely, after the 5th – 6th semester there is a heavy load of mandatory laboratory experimentation which enforces student attendance, but beyond this students are readily oriented toward a specialization and thus their motivation is gradually increasing.

In view of the above it is by now obvious that the Greek EECE currently employ the so – called "Teacher – centered curriculum" and most of its first years low educational performance could be attributed to this specific learning model.

The two important observations that the educational performance is increased during the semesters including laboratory or design exercises, achieving its peak within the work toward the diploma thesis, clearly leads to the necessity of changing the system by employing a "Project – problem based learning (PBL)" within the proven "Student – Cantered" curriculum. However, let us be a little conservative, exactly as engineers have always been. In this view I share the opinions of Duran et al from the University of Malaga (Spain), [2]. In [2] and the original references therein it is stated that in an ideal teacher – centred model: "the teacher manipulates the learning situation to obtain the desired outcomes guided by generalized characteristics of the learners" thus "it leads to rote learning and stifling of critical and creative thinking", [2]. This is an obvious advantage that should not be abandoned. However, within this model students do not realize the usefulness of what they are taught (particularly during the preparatory first four semesters) and its relation to industry applications, thus their motivation is diminished, [2]. Thus the serious poor students performance and their low motivation should be drastically confronted employing the tools of "project based approach" and the "learner – centred approach" with the aid of new educational technologies. My understanding and thoughts are very much in line with those of Duran Et al [2], namely "to combine these new learning features toward the enhancement of traditional methodology".

3. REFORMING UNDERGRADUATE EECE CURRICULUM

Before going into the definition of specific action to be suggested for the core and flows curriculum, let us review the general framework as elaborated by the international engineering bodies. First regarding the duration of engineering education both in Europe and United States Engineering educational boards have strongly stated that 4 years are not enough, 5 years are required at least ,while when aiming at engineers to act as leaders or Policy makers 6 years are mandatory [3-8]. The latter argument is particularly stressed in [4],while according to Vests [3], MIT started before 1995 a new integrated 5 years leading to a Master of Engineering degree (M. Eng.) rather than the traditional two cycle BSE (four years) possibly followed by Master of science in Engineering (MSE, usually requiring one and a half year). The M. Eng. is "more of a practice than a research oriented" and according to vest it became the preferred route for most students, [3].

In Europe there was a joint effort of European educational institutions (SEFI, CESAER, CLUSTER) toward the recognition of the integrated 5-years engineering programmes as leading straight to a Master Degree in Engineering [7,8]. This initiative is in accordance with the latter engineering educational directions in US as described above. Furthermore, SEFI's opinions [7] states that "There is today a high degree of consensus that the professional engineering degree should take about five years following secondary school". Additionally, CLUSTERS statement [9] stress that "Typically, a Bachelor degree (3 to 4 years) will correspond to engineers who are "employable" , but are not professionals, while below they stated that "the Master's degree corresponds in most institutions to the Engineering Diploma". In my opinion the above views reflect exactly the views and recognition tasks adopted by all Greek EECE departments-schools. In any case all recent evolutions in engineering education as described above, ensure that the already employed "integrated five years engineering education" fulfils the current as well as future trends and should be retained along with a joint effort toward the recognition of the engineering diploma equivalence to M. Eng. However, the

EECE curriculum should be reformed to include the recent learning and convergence trends along with the adoption of appropriate quality accreditation. A wide consensus of the Engineering community and boards is observed in regard to reforming engineering curriculum toward, e.g. [3, 4, 6]:

i) De-emphasize narrow disciplinary approaches and strengthen thought along inter-disciplinary lines. Utilize a problem – solving approach to support this task.
ii) Retain and possibly strengthen a solid basic engineering knowledge. The report [5] even suggests the adoption of a 4 years core courses plus 1 year specialization in the integral 5 years professional (M. Eng.) degree.
iii) Educate engineers to work better in groups and the best way is through the problem solving based learning.
iv) More emphasis should be put on design and not to be restricted in the analysis. Namely, to strengthen the students hands-on engineering experience as “design-build-operate”. This means not only to enhance the laboratory exercises but to carefully select problems from the real world-industry applications within the PBL approach.
v) To include courses on economics, marketing and management in the curriculum, which will improve engineers employability but also strengthen their skills toward solving interdisciplinary problems and improve communication when working in teams.
vi) Prepare engineers to act as policy makers and leaders by including courses on Ethics and public policy, [6]. These courses may contribute to the realization of legal and moral responsibility of Engineers in their professional practice.
vii) According to [5] try to “Infuse more professional content into existing engineering programmes”. This is already adopted by MIT and Stanford through the appointment of Engineers with distinguished carriers in industry as *“Professors of Practice”.*
viii) Prepare engineers for lifelong learning or one could say “teach them how to learn and they will carry on to acquire more knowledge than their educators”. Keeping in mind the above and using them as guidelines, we will try to suggest the first steps of the required undergraduate curriculum reforms.

4. SPECIFIC SHORT TERM ACTIONS

Initiatives to be taken should address the weakness of the core courses and the specialization part of the curriculum. The main weakness of the core courses are the low motivation of students and hence their low attendance in the lectures. This can be confronted by trying to shift from the exclusively teacher – centred toward the student or learner – centred model. For this purpose two actions are suggested:

1st) Introduce into theoretical courses of mathematics – statistics, physics and electromagnetism problems from the technological courses of the higher semesters. These problems should span the whole range of specialization courses from power systems and electronics to communications. For each significant theoretical subject there should be an engineering problem to be solved with the aid of software packages like matlab, mathematica and spss. The problem should be formulated into a step –by – step approach so that students be able to setup a mathematical model: differential equation, system of equations, eigenvalue problem, an integral or a statistical – probabilistic problem, starting from the specific engineering problem. In turn this should be solved analytically for one simple case and numerically for one realistic case. Students can work in teams for this scope but each one of them should be responsible for a specific part of the project. For the working approach there should be meetings of the teams in a form similar to that of laboratory exercises at least once at the beginning and once at the completeness of the project which should be accompanied by an oral presentation where each member of the team presents his/her contribution. Intermediate meetings could be also arranged with the responsible teaching assistant. It is important to note that this learner – centred approach will run in parallel with the traditional lectures of the teacher – centred model. Actually they will be scheduled within the "laboratory" and homework exercises. In this manner we aim at combining the best features of each teacher – and learner – centred model, mainly by expecting an increase in students motivations and hence an improvement of their attendance in the lectures. The reasoning behind these ambitions is that students will realize their lack of specific knowledge which they will try to acquire from the teacher – lectures.

2nd) Enhance the electrical engineering-technical core courses through the problem based learning approach. Recently the undergraduate electrical engineering programmes are reformed but with the emphasis was put in the core courses. Aiming at a *"solid engineering background*" an attempt was made to include in the first 6 semesters all basic electrical engineering knowledge as far as was possible, spanning from: electrical power systems, electronics, telecommunications and computers-software. The purpose was to supply the young engineer the knowledge and the skills so that he/she will be able to adapt to any one of the following specializations and be prepared for life-long learning. The degree up to which this was achieved will be found out during the next self and external evaluations of the programme. However, there were some obvious problems from the beginning. First, it was it was found out that the required "basic knowledge" cannot be given in the first 6 semesters (3 years) and this observation is in accordance with that of the report [5] which talks about 4 years of required core courses. Regarding this option we have to wait for the evaluation results and rethink about it. The second observation is that the electrical engineering courses in the core lack the essence of the project – based learning approach and in particular the "design-build-measure-test" methodology. Toward this direction we do not have to re-invent the wheel, but just to adopt already tried projects by other programmes, e.g. [2, 10-13]. Besides, we have to keep in mind that the students must work in teams and the projects must span the wide spectrum of electrical engineering applications as far as possible. On these bases the projects must include problems from: i) electrical machines and power systems, e.g. [2], ii) circuit analysis and design, e.g. [11], iii) computational and software, e.g. [13, 15] iv) microelectronics, high speed-microwaves circuit analysis and design and v) Telecommunication circuits design.

The methodology elaborated at the EECE department at the University of Malaga seems a good starting point which according to [2] includes the steps: "*presentations of the project* (in a lecture), *challenge the students to solve some questions*, *brainstorming and collection of ideas, simulation-visualization-solution, discussion and theoretical explanation*". Additionally, methodologies elaborated at other universities will be studied, e.g. Stojcevski [14], but also the Greek industry needs as well as its development prospects will be taken into account.

Returning back to the specializations starting at the 7th semester and completed with the 10th semester diploma thesis, these should address all the sciences convergence trends, along with the needs for the engineers readiness for interdisciplinary professional activities. By carefully going through the previously depicted guidelines and particularly no. v through viii it seems that these can be best served through the adoption of the 14 flows already employed at the EECE school of NTUA – Athens, [16]. Both the interdisciplinary convergence (Health Sciences, Physics and Engineering) and the intra – EECE convergence (e.g. smart grids, software defined-cognitive radios: SDR-CR) can be supported by completing three of these flows or two complete and two half flows. A very delegated point which should receive high attention is that this specialization should include all characteristics of a Master of Engineering, in particular 8 courses on a specific standalone topic which will form the knowledge base for the diploma thesis to be founded on them.

A careful study of the health sciences and engineering convergence and the impact that is expected to have on the Human progress and society well being, reveals that this cannot be sufficiently supported through the above flows –flows nor can be fulfilled at an undergraduate or M.Eng. level. Hence, an interdisciplinary cooperation between the engineering and the medical school as well as industry activated in Bioengineering and related research institution should be pursued. The first task to be put forward is the organization of a graduate Bioengineering programme founded in these principles.

Returning back to the above 14 flows-flows, even they constitute the desired framework they are currently implemented on a teacher – centred model, thus they should be enhanced towards including a project based learning approach. For this purpose realistic projects should be adapted from real industry problems to be included in the curriculum. It is foreseen that this could be accomplished through one "group-design-project" per semester (three in total for the 7^{th}, 8^{th} and 9^{th} semesters). Each track-flow should incorporate at least two different projects for the student-teams to select one of them. These projects must be continuously updated following the evolution in science and technology.

5. SUMMARY & CONCLUSIONS

It is widely realized that engineering education faces a substantial change trying to address the economy globalization as well as the interdisciplinary sciences convergence. Solid engineering education must be retained, while during their education they must acquire hands-on experience in *"design-build-operate"* through projects. Additionally, engineers must be prepared to become leaders and policy makers thus they should have knowledge of basic economic, marketing and managerial topics enriching their "soft-skills" or communication abilities. Some first steps toward enhancing the Greek EECE curriculum have been proposed herein for both core and specialization courses. Two are the major challenges, to include project-based learning through the entire curriculum and to adopt a number (14) flows – flows in the specialization able to support the evolving convergence of sciences but before all to support the engineering diploma equivalence to a Master of Engineering degree. Finally, a cooperation call is addressed to all colleagues and in particular to SEFI leadership to support our claim to Greek government and the European Union for a recognition of all integrated systems engineering diplomas as equivalent to a Master of Engineering (M. Eng.), provided that they have undergone the appropriate accreditation.

REFERENCES

[1] MIT white Paper, "*The Convergence of the Life Sciences, Physical Sciences and Engineering*", available online www.cimit.org/.../MIT-White-Paper-on

[2] M. Duran J. Aguado, S. De La Torre and S. Martin, "An interactive project – based learning teaching methodology in electrical engineering courses", available online.

[3] Charles M. Vests, "U.S. Engineering Education in Transition", address the National Academy of Engineering on Sept. 1995. Available online at http://web.mit.edu/president/communications/NAE-9-95.html .

[4] US Board on Engineering Education, "Engineering education: designing an adaptive system", National Res. Council Rep., Washington, DC: National Academy Press, 1995,

[5] James J. Duderstadt, "Engineering for a changing world: A roadmap to the future of engineering practice, research and education", the millennium project, University of Michigan, 2008. Online at: http://milproj.dc.umich.edu/ .

[6] Günter Heitmann, Aris Avdelas and Oddin Arne, “”Innovative Curriculum in Engineering Education”, Firenze University Press 2003, online at http://epress.unifit.it/

[7] SEFI’s opinion on the “Joint declaration of the European Ministers of Education, signed n Bologna”, Brussels, 4th December 2000.

[8] CESAER, SEFI and CLUSTER, “Joint letter to Ministers of Education meeting in Prague on May 17”, May 9, 2001.

[9] CLUSTER “Statement on the implementation of the Bachelor/Master’s model”, Turin assembly of May 23&24, 2003.

[10] A. Stojcevski and R. Veljanowski, “Electrical Engineering & PBL: from a teacher – centred to a student – centred curriculum”, in Aung, W et al (eds), Innovations 2007, iNEER/Begel House, Arlington VA, USA

[11] L. R.J. Costa, M. Honkala and A. Lehtovuori, “Applying the problem – based learning approach to teach elementary circuit analysis”, IEEE Trans. on Education, vol. 50, pp. 41-48, Feb.2007.

[12] D.L. Maskell and P.J. Grabau, “A multidisciplinary cooperative problem – based learning approach to embedded systems design”, IEEE Trans. on Education, vol.41, pp. 101-103, May 1998.

[13] G.K. Kumar Venayagamoorthy, “A successful interdisciplinary course on computational intelligence”, IEEE computational Intel. mag., pp. 14-32, Feb. 2009.

[14] A. Stojcevski, “Learning to solve design problems in engineering education”, available online: http://www.sefi.be/wp-content/abstracts/1204.pdf

[15] D.T. Rover, R.A. Mercado, Z. Zhang, M.C. Shelley and D.S. Helvick, “Reflections on teaching and learning in an advanced undergraduate course in embedded systems”, IEEE Trans. on Education , vol. 51, pp.400-412, Aug. 2008.

[16] School of Electrical and Computer Engineering, National Technical University of Athens, “Curriculum Guide 2009-2010”, available online at: http://www.ece.ntua.gr/images/stuff/cg.pdf