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Engineering education reform: the imperatives for ensuring its quality and outcomes

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ABSTRACT: Leading scholars, researches and educators have been involved in discussions concerning the need for reforming engineering education in accordance with the changes and needs of industry, business, commerce and public services. The recognition of the rapid expansion of scientific and technical knowledge caused by the development of information and communication technologies, as well as the vast opportunities to study, work and live anywhere in the globe, are the driving forces for re-evaluating the basic concepts of engineering education. It is important to emphasise that the idea behind this reformation initiatives is to define the rational goals of engineering education, identify and assess the outcomes and level of proficiency, and to develop a unified curriculum. Such a curriculum would be easy to customise according to the specific educational needs and provide the quality of education by improving engineering pedagogy, including teaching approaches, methods and techniques. The growing concern about the quality of engineering education stimulates the efforts by many initiative groups to remedy the situation and those efforts are encouraged by industry and government. Some attempts to contribute to the reform of engineering education are described and discussed in this article.

INTRODUCTION

Those who follow relevant scientific publications and research concerning engineering education would agree that the idea of engineering education reform has been advocated for some time now, and is long overdue. Particularly stressed is the necessity to bridge the gap between engineering education and engineering practice. In other words, it is the effort to re-evaluate the goals and objectives of engineering education, develop a curriculum compatible with the industry needs and implement the strategy to achieve the required level of proficiency within the defined outcomes, so that any graduate could make a significant and influential contribution to the engineering practice of the 21st Century.

Moreover, the continued accreditation of educational programmes and university ranking processes complement the process of ensuring the quality of engineering and technology education, thus providing equal opportunities for engineering graduates. For engineering education, it is the time of ferment and argument, as well as the development and evolution. It is the time for the innovative minds in engineering education to change their paradigm by building a framework of revised theory, research and implementation.

SIGNIFICANT INITIATIVES OR GREAT REFORMERS

All the initiatives to reform higher education should be viewed against the backdrop of the global changes and needs in industry, business, commerce and the public services. The globalisation process brings about the dominating idea of unifying educational systems and standards without losing the quality of education.

In 1999, Ministers of Education from 29 European countries signed the document called the *Bologna Declaration*, which marked the beginning of the reformation of the European higher education area. In the Declaration, several important objectives have been specified as follows:

- The adoption of a common framework of readable and comparable degrees, *also through the implementation of the Diploma Supplement*;
- The introduction of undergraduate and postgraduate levels in all countries, with first degrees no shorter than three years and relevant to the labour market;
- ECTS-compatible credit systems that also cover life-long learning activities;
- A European dimension in quality assurance with comparable criteria and methods;
- The elimination of the remaining obstacles to the free mobility of students (as well as trainees and graduates) and teachers (as well as researchers and higher education administrators) [1].

It looks like the whole idea of that reform is about unifying the structure of higher education and increasing mobility because there should be *a common European answer to common European problems*. It is also said in the document that *the fundamental principles of autonomy and diversity are respected* [1].

The major concern about this initiative is the deficit of information about the outcomes, especially statistical data and analyses of success and failures. One of the examples is the situation in Greece, where the government met strong opposition on the part of students as a reaction to massive and radical reforms in the education sector in accordance with the *Bologna Declaration*. This social tension was the reflection of the younger generation of graduates on the perspective to be unemployed due to being part of a *flexible labour force*. Therefore, they carried the slogans *Public and Free Education* and *We Want Jobs, Not Unemployment* [2]. This situation shows that in order to meet the goals of the *Bologna*

Declaration, some governments may blindly sacrifice peace and stability in the social sector.

Furthermore, the unification of the organisational structure of European institutions with their preserved identity will hardly make it possible to provide education of the same quality. If the question is in recognising the level of proficiency, then this reformation process should probably be more about developing standards and providing quality.

The Accreditation Board for Engineering and Technology (ABET) in the USA has provided leadership and quality assurance in higher education for over 70 years. It is the most widely recognised accrediting organisation for assuring that an education programme meets the quality standards established by the profession for which it prepares its students. The ABET quality standards are set collaboratively by many different professional and technical societies working together through ABET in order to develop those standards and provide an evaluation of whether the programmes meet the ABET's standards [3].

Another key initiative, known as CDIO (Conceive - Design - Implement - Operate), emerged in October 2000 in order to improve engineering education worldwide. The name of this international collaboration group is derived from the product/ system lifecycle definition, which reflects the whole idea of the contemporary engineering education rationale as follows:

> *Graduating engineers should be able to conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment* [4].

A simple statement that *engineers engineer,* ie *they build systems and products for the betterment of humanity*, was justified by the CDIO Initiative as the main principle to build their research upon and develop the CDIO Syllabus content [5].

As shown in Figure 1, engineering students are expected to have the knowledge, skills and attitudes necessary to *Conceive – Design - Implement - Operate*. It is believed that the *Personal and Professional Skills* component is central to engineering practice. The appropriate *Technical Knowledge and Reasoning* element in the portfolio of an engineering graduate should give him/her freedom to develop complex value-added engineering systems. The *Interpersonal Skills* part of teamwork and communications are essential for working in a modern team-based environment. Finally, it is important that students understand the principles of conceiving, designing, implementing and operating systems in the enterprise and societal context [5].

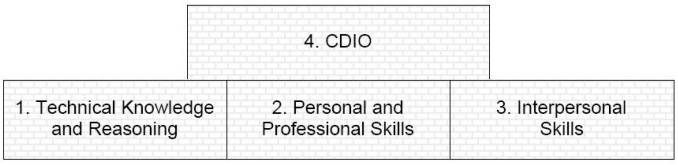

Figure 1: The building blocks of knowledge, skills and attitudes necessary to conceive, design, implement and operate systems in the enterprise and societal context [5].

The CDIO Syllabus is a *codification of contemporary engineering knowledge and attitudes* that correlates strongly with the ABET Criteria EC2000, as presented in Table 1 [6].

Table 1: The ABET 2000 Requirements correlated with the CDIO Syllabus [6].

CDIO Syllabus Sub-section	ABET Criteria Met										
	a	b	c	d	e	f	g	h	i	j	k
1.1	●										
1.2	●										
1.3	□										●
2.1					●						□
2.2		●									
2.3			□								
2.4									●		
2.5						●					□
3.1				●							
3.2							●				
4.1								●		●	
4.2											
4.3			●								
4.4			●								
4.5			●								
4.6			●								
● Strong Correlation							□ Good Correlation				

By the look of this correlation and comparison, it can be concluded that the CDIO Syllabus is even more comprehensive and explicit. The CDIO Syllabus is not merely descriptive, ie is pointing out certain outcomes, but it has several explanatory levels that gradually lead to the topical version of the Syllabus content. Such a detailed organisation of the Syllabus makes it flexible for the customisation according to the stakeholders' specific needs.

It should also be noted that, in order to translate the list of topics and skills into learning objectives and adapt the Syllabus to a degree programme, it is required to conduct a survey determining the desired level of proficiency in the designated skills [6].

A comparative study of expected student proficiency was carried out by four universities, the original developers of the CDIO Initiative, namely Chalmers University of Technology, the Royal Institute of Technology and Linköping University, all in Sweden, as well as Massachusetts Institute of Technology in the USA. The survey was conducted among four constituencies: faculty, senior industry leaders, young alumni (average age 25) and older alumni (average age 35). After comparing the results, it was concluded as follows:

> *The survey indicates that the skills for which the proficiency expectations are the highest include engineering reasoning, personal attributes, communications, and design. These four skills are consistently among those cited as most important in a young engineer. At the Swedish universities, the expected proficiency in Communications in Foreign Languages also was high* [5].

What is really welcoming about the CDIO Initiative is the transparency and openness. All the information about the reform itself, approaches, surveys, outcomes, publications and

even the contact details of the people involved in this project, are available free of charge from the CDIO Web site [7]. The essence of globalisation is in its openness, freedoms and flexibility. Hence, if the idea is to re-evaluate and improve engineering education globally, it has to be openly provided and supported with information, research-based findings and expertise.

FROM RADICAL IDEAS TO REAL PRACTICES

The immediate and more distant future of university graduates is to be fully and professionally engaged in global society, enterprise and commerce. The quality of education that they obtained will impact directly on their recruitment drive, and the capacity to further develop professionally and achieve high living standards. Hence, the understanding of these challenges creates the tendency for educational institutions to revisit, re-evaluate and reform the educational programmes that they offer. International initiatives contribute to this process a lot by providing education quality standards and expertise.

ABET currently accredits some 2,700 programmes at over 550 colleges and universities, both nationwide and worldwide. According to the ABET statistical data, as displayed in Table 2, it can be stated that there is a large number of institutions involved in the accreditation process and the number is growing each year [3].

The accreditation of engineering programmes by ABET is voluntary. The programme of an institution, which seeks accreditation, is assigned to one of four accreditation commissions within ABET, specifically the Applied Science Accreditation Commission (ASAC), Computing Accreditation Commission (CAC), Engineering Accreditation Commission (EAC) or Technology Accreditation Commission (TAC). Each Commission has different accreditation criteria.

It can be observed from the ABET statistics data listed in Table 2 that the EAC is very heavily loaded with the number of programmes and institutions that seek accreditation. It is also presented in Figure 2 that the number of programmes assigned to the EAC is still growing [3]. It demonstrates the awareness of society about the importance of engineering education for its welfare and development, as well as highlights the growing concern about the quality of engineering programmes and the intention to grasp the reality of global needs.

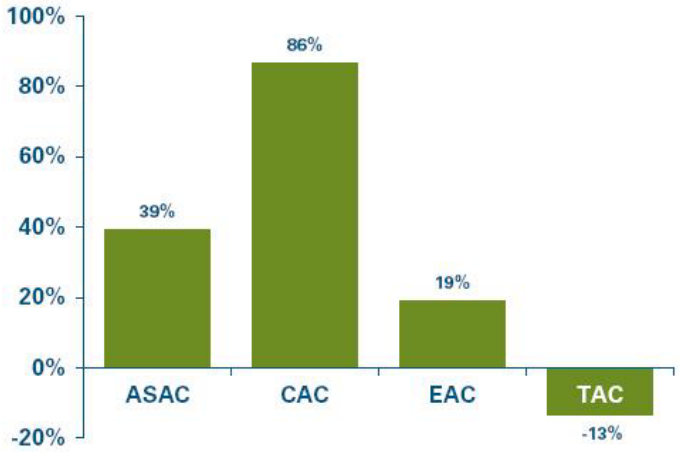

Figure 2: The increase/decrease in the number of accredited programmes (1996-2006) sorted by the Commissions [3].

As far as the CDIO Initiative is concerned, it is quickly gaining momentum. It complements the efforts of accreditation bodies in changing the face of engineering education for the better. There are 24 collaborating schools on board the CDIO Initiative. As it is stated on the CDIO Web site:

> *The CDIO™ Initiative was developed with input from academics, industry, engineers and students. It is universally adaptable for all engineering schools. CDIO™ Initiative collaborators throughout the world have adopted CDIO™ as the framework of their curricular planning and outcome–based assessment. The CDIO™ Initiative is an innovative educational framework for producing the next generation of engineers* [7].

The recognition of the necessity to incorporate the enhancement of global competences into engineering curricula has become a reality and is well accepted. There are a number of national initiatives that work together on improving the quality of education to better prepare engineering graduates for global practice. Lohmann et al recognise the fact that:

> *While many aspects of society and commerce have become internationalized, it cannot yet be said for many university curricula that they prepare students to live and work in a global community, especially engineers. Incorporating international preparation into engineering curricula, however, has proven to be a major challenge* [8].

Table 2: Number of programmes accredited by ABET and institutions with accredited programmes, 1996-2006 [3].

	ASAC		CAC		EAC		TAC		All	
Year	Programs	Institutions	Programs	Institutions	Programs	Institutions	Programs	Institutions	Programs	Institutions
1996	51	36	140	136	1,502	312	774	249	2,467	541
1997	55	39	144	139	1,531	315	771	250	2,501	545
1998	59	44	149	144	1,539	317	776	248	2,523	548
1999	58	45	155	150	1,552	320	730	238	2,495	544
2000	59	45	163	158	1,581	323	718	238	2,521	549
2001	60	45	169	164	1,618	332	711	239	2,558	557
2002	62	47	181	171	1,664	341	694	237	2,601	561
2003	66	48	197	181	1,700	343	679	226	2,642	554
2004	70	51	215	193	1,750	350	702	230	2,737	562
2005	66	50	239	204	1,759	357	664	220	2,728	571
2006	71	54	261	220	1,787	364	670	226	2,789	587

They go on to say that in the USA, several universities have developed programmes designed to prepare students to perform their professional activities on the global scene, as follows:

> *These programs fall into four categories: co-majors or dual majors (e.g. Pennsylvania State University, Iowa State University and University of Rhode Island), minors or certificates (e.g. Iowa State University, Purdue University, University of Illinois, University of Michigan and University of Pittsburgh), international internships or projects (e.g. Worcester Polytechnic University and Pennsylvania State University) or study abroad (e.g. University of Minnesota)* [8].

There appears to be a lot of support for, and contribution to, the research, development and implementation of modern engineering curricula, which have to be designed as a common model, and are easy to be customised and adapted to specific engineering needs.

A FOREIGN LANGUAGE FOR ENGINEERS IS NOT A LUXURY BUT A MUST

Living in the global context of the 21st Century is challenging as it does not only require a young engineering graduate to be technically adept, but also have the knowledge and skills to function efficiently in a transnational engineering environment. It places great emphasis on the acquisition of language and communication skills. Some important considerations on improving the acquisition of communication skills by engineers have been discussed elsewhere [9].

It should be recognised by universities that there is still not enough attention being paid to incorporating language skills into engineering curricula. Yet people who have science and technology subjects in combination with languages are particularly sought after by employers because any serious business or enterprise today is a part of the global economy.

In this context, it is surprising to see that the MIT did not even include foreign languages when conducting the survey for the CDIO project on the levels of proficiency [5]. It is seen to be odd due to the fact that in the 1960s, Noam Chomsky and his MIT colleagues were at the theoretical forefront of applied linguistics. The authors are puzzled by the fact that those outstanding linguistic scientists and scholars with enormous achievements and reputation had no influence over this process.

The myth that English is a *lingua franca* has been busted by the presented statistic figures which show that 75% of the world's population do not speak English at all [10]. Moreover, the statistics show that only 5% of the world's population use English as their first language [11].

According to the survey carried out by Hobsons Agency, the English-speaking world faces such difficulties as a shortage of native English speakers for jobs at all levels. Only a third of UK graduates have the confidence to go abroad to find work. Two thirds of their continental colleagues feel that they are able to do this and venture into the global job market [12].

This deficiency in education is of great concern to some educational institutions that find their way to incorporate foreign languages and communication skills development into their curricula. Lohman et al state the following:

> *The University of Rhode Island offers a five year dual degree in engineering and language (German, French or Spanish). In addition to meeting the requirements for the language and engineering degrees, students spend an academic year outside the USA, either on an internship, studying at an exchange university or undertaking a combination of study and internship. Among all universities reviewed, the Rhode Island program provides the most extensive language study, study of another culture (through advanced language courses) and the longest period of study overseas* [8].

It should be noted that the International Engineering Program (IEP) at the University of Rhode Island was launched in 1987 and, since then, it has been functioning successfully. Initially, the IEP was limited in terms of the offered language to German only. In order to instil the second degree into the engineering programme, the duration of the IEP had to be expanded to five years. Another basic element of the IEP was an internship in a company in a German-speaking country for the duration of six months in the fourth year [13]. Today, in addition to the German course, the IEP also offers the second degree in French and Spanish, as well as in other languages, for example Chinese, which has emerged together with the international expansion of the US trade market.

In evaluating the success of the programme, J.M. Grandin, the IEP Director, stated the following:

> *The program boasts a 100% placement rate and, frankly, cannot keep pace with the worldwide need for engineers with cross-cultural communication skills* [14].

It seems that the necessity of incorporating foreign language competences into engineering curricula as one of the important outcomes cannot be regarded as a tribute to globalisation fashion but a necessity dictated by international businesses and trading activities. It was one of the reasons why, from the very beginning of the project, the IEP received a wide acceptance, as well as significant support and willingness to help from companies and governmental organisations [13].

The same goals and objectives are being pursued by the American Council on the Teaching of Foreign Languages (ACTFL), which is committed to building language proficiency, and which has the following notion in its mission statement:

> *ACTFL is the only national organization dedicated to the improvement and expansion of the teaching and learning of all languages at all levels of instruction throughout the US* [15].

It also provides expertise, advocacy, resources and standards concerning the level of language proficiency.

Another quite successful programme called Communication across Curriculum (CxC) appeared as a means to reinforce communication strategies and integrate communication into existing engineering curricula. It was basically a response to one of the ABET Criteria 2000 requirements, which states that the engineering graduate should demonstrate the ability to communicate effectively. There are several universities that contribute to the effort of addressing this issue in practice;

among them are Louisiana Sate University, USA, the University of Pittsburgh, USA, and others.

The National Centre for Languages (CILT) was created in the UK in order to promote the true value of the languages at workplace. According to the survey by the CILT:

> *… one in five UK companies involved in export or import is losing business because of language and cultural barriers. There is evidence from CILT surveys that employees need language skills throughout the organisation, and this is very often in the frontline – the first point of customer contact* [16].

The Languages National Steering Group in the UK makes a considerable input into the development of the strategy to transform the country's capability in languages. The Group has worked out the language strategy for England, which outlines the Government's plan concerning the language acquisition and gives an insight into the initiatives to *broaden and enrich the opportunities for language learning at school and beyond* [17].

CONCLUSIONS

It is a widely recognised fact that being a part of the global economy, a lot of changes are being brought to the social and professional environments, as well as many challenges evoked within the education system in order to keep the momentum and provide high quality education. It should also be understood that foreign languages and communication skills, although not primarily engineering skills, should not be neglected in curricula.

This is especially important when taking into account that linguistics develop other skills such as risk taking, thinking flexibility, dealing with the unexpected and working across communication boundaries. Moreover, the motivation of students to learn foreign languages could be boosted when demonstrating to them the statistics from recruitment agencies, which state that salaries for those using languages at work can be much higher by 8% to 20%, when compared with those without such skills, depending on how central languages are to the role [16].

Research carried out so far has found that there are many international initiatives and programmes with the objectives to contribute to the changing paradigm of engineering education. Their principles and undertaken efforts may differ in some aspects but the main objectives are similar. Most of the initiatives endeavour to develop universal curricula through which to raise proficiency standards in order to allow engineering graduates to gain the requisite knowledge, skills and attitudes progressively as their careers advance.

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Conference Proceedings of the
10th UICEE Annual Conference on Engineering Education
under the theme:
Reinforcing Partnerships in Engineering Education

edited by Zenon J. Pudlowski

The *10th UICEE Annual Conference on Engineering Education*, held under the theme of *Reinforcing Partnerships in Engineering Education*, was organised by the UNESCO International Centre for Engineering Education (UICEE) and was staged in Bangkok, Thailand, between 19 and 23 March 2007, at the Menam Riverside Hotel.

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