UDC 378.141.214

European perspectives on the competences of engineering graduates

Commission of certified engineers (CTI), France
B. Remaud

The input-based approach to engineering education, which was the rule during the last century, is being replaced by the ouput-based approach for the design of the programmes as well as for their accreditation. In many institutions, the competences description seems close to a layer over the traditional pedagogical approaches; in particular, the definition and the assessment of the transferable skills are diversely implemented. We present and discuss the state of art in the French engineering education, and a survey to study the impact of these new approaches on the young engineers.

Key words: *Engineering education, competences specification and assessment, impact on graduate engineers.*

B. Remaud

Introduction

In the nineteenth century, a model of university emerged in Europe, it is often referred to as the Von Humboldt model, because this famous geographer was its most prominent promoter. The concept of « Humboldtian » university used today agglomerates several elements including the following (see S. Paletschek [1]):

- the unity of research and teaching;
- the function of the university as a research institution;
- the freedom of research and teaching which allows the university to function in furthering pure science (which is to say a science free of vested interests);
- the assumption that science provides moral education.

The university in this context relies on a faculty staff dedicated "without compromise" to pure science and personal culture, "the teacher is not there to serve the student, but both must serve the research of knowledge" [2].

In contrast, the model of a university which is dedicated to social progress and applied knowledge has been promoted by E.N. Whitehead in 1929 (see ref.11).

But the culture of a university dedicated to knowledge and free of any constraint seems deeply rooted in the faculty of many universities in Europe: academic freedom is often invoked, the research of consensus within the faculty is the rule, the outside world (enterprises, local and national authorities) is barely associated with the governance of colleges and universities; the concern for academic excellence for training is raised to its highest level (including the training of engineers).

The vision of the university currently supported in Europe seems almost the antithesis of the Humboldtian vision. In a recent report [3] of the European Commission "Rethinking Education - Investing in Skills for better socio-economic outcomes", it is written that "investment in education and training for skills development is essential to boost growth and competitiveness, skills determine Europe's capacity to increase productivity". And further "European education and training systems are not working adequately with business or employers to bring leaning experience closer to reality of the working environment".

The Commission gives four axes of efforts to improve the situation (for all education cycles education, not only for the universities):

- Developing world-class vocational education and training to raise the quality of vocational skills.
- Promoting work based learning including quality traineeships, apprenticeships and dual learning models to help the transition from learning to work.
- Promoting partnerships between public and private institutions (to ensure appropriate curricula and skills provision).
- Promoting mobility through the proposed Erasmus programme for All.

Engineering departments (or applied sciences departments) in Europe must mediate between the demands of their academic missions and their missions concerning the employability of their graduates, their contribution to the national economic development and their contribution to solve global problems that the world has to face in the future.

Depending on the academic traditions and the political contexts in their respective countries, engineering departments have different ways to arbitrate between the two extremes: on the one hand, an engineering course based on scientific excellence -including research- to educate, critical and responsible individuals, who have to define after their studies their career path; on the other hand, training of scientists for business, having a solid scientific basis but also trained for their future responsibilities.

Within this diversity, however, trends are emerging at the global level. These trends are the result of underlying constraints such as the globalization of the world economy, the globalization of environmental problems, the student and graduate mobility (professional mobility throughout life and geographical mobility).

These trends lead in all countries to training of engineers, less expert in a specific field, but open to cultural diversity and more likely to consider the problems in their entirety (technical, but economic and societal).

In this context - as is natural in a worldwide market- setting standards and guidelines becomes mandatory to facilitate international transparency of courses (not their homogenization), to establish the comparability of objectives and of learning outcomes for the graduates.

Competences of graduate engineers and Quality Assurance

"Competences" and "Quality Assurance" are general keywords which are sometimes interpreted differently, depending on the context; we use the definitions by ENQA [4].

Competences represent a dynamic combination of knowledge, understanding, skills and abilities. Competences are developed and acquired by the students during the educational process. Some competences are subject-area related (specific to a field of study), others are generic (common to any study programme).

The concept of competence is associated with the concept of learning outcomes, which are statements – made by the academic staff – of what a learner is expected to know, understand and/or be able to demonstrate after completion of a process of learning. Learning outcomes have to be expressed in terms of the level of competence (knowledge, understanding, skills and abilities) to be obtained by the learner

Finally, "quality assurance" refers to a "continuous process of evaluating the quality of a system, an institution or a program of higher education." Quality assurance, as a process, focuses on both accountability and continuous improvement by providing information and judgements (no ranking) through defined processes and pre-agreed criteria.

In a very comprehensive report, OECD [5] has published a global cross-sectional analysis of learning outcomes for engineers, in particular, to extract common elements recognized at the international level. The report provides a comparative analysis of the EUR-ACE standards [6] and ABET [7]; beyond differences in wording, sometimes differences of emphasis, there is a broad consensus around six themes:

- Knowledge and Understanding for the bases in mathematics and science underlying all engineers training; EUR-ACE includes the need for fore-

front knowledge in a leading sector and for transdisciplinarity.
- Engineering Analysis: refers to the ability to apply knowledge to the resolution (identification, formulation, resolution) of engineering problems (products, processes and methods).
- Engineering Design: is the ability to solve problems in satisfying the constraints; ABET specifies the constraints (economic, environmental, social, political, ethical, health and safety).
- Investigations: only specified by EURACE, refers to the ability to conduct searches of literature, and to use data bases and other sources of information.
- Engineering Practice: refers to the ability of the theoretical and experimental tools for solving problems, be aware of their limitations and their implications for non-technical (EURACE) or understand their ethical and professional (ABET).
- Transferable Skills: concerns a wide domain, where are the capacities or abilities to function effectively as an individual and as a member of a team; to use diverse methods to communicate effectively with the engineering community and with society at large; to demonstrate awareness of the health, safety and legal issues and responsibilities of engineering practice; to demonstrate awareness of project management and business practices; to engage in independent life-long learning.

The "learning outcomes" are results-oriented; the quality assurance is more process-oriented, it aims to organizing the continuous improvement of programmes and of institutions (and of the accreditation agencies) and to provide the foundation for mutual trust between institutions of different countries.

Impact on academia and institutions

The switch from a program-based to a learning outcomes-based approach of engineering education has deep consequences for the university teachers and for the management of the universities and their departments.

This new approach is like a Copernican revolution for teachers, a shift that is a source of concern or of resistance to change. The programmes do not result from the concatenation of the professors' specialities, but from a global project where the learning outcomes are determined to prepare graduates to their professional career.

Quality assurance, with its feedback loop for continuous improvement, requires a participatory but strong governance for the institution. A quality assurance process should be based on a broad consensus within the institution, everybody sharing the objectives and methods. But the improvements may not result from the simple addition of individual goodwill; choices -sometimes painful for someone-, must be made by a legitimate and informed authority.

In many countries, the universities are managed by large assemblies where all the bodies are represented (especially teachers, students most often, technical and administrative staff sometimes). This model seems hardly compatible with the accepted global guidelines for the education of engineers: the definition of the targeted competencies, the acquisition of non-technical skills, the training in engineering fields, cannot be conceived without a wide opening of the institutions and programmes to representatives of society (employers, local authorities, government).

For example, the recent release of European Ministers of the EHEA (Bucharest 2012) gives one of the priorities for 2012-2015: "working to improve employability, learning throughout life, the ability to problem solving, entrepreneurial skills, through enhanced cooperation with employers, especially for the development of training programs". This recommendation applies to all university domains; it has a particular resonance for the training of engineers.

Although, there is a global agreement on the principles of QA and competences approach, their concrete implementation is highly variable depending on the countries and on the institutions. Programme managers need to arbitrate between multiple constraints:
- Share of training time between scientific matters and transferable skills.
- Arbitration between the objective of academic excellence in a domain (each professor is convinced that his/her domain is at the forefront) and

the training to broad multidisciplinary domains.
- Arbitration between traditional pedagogical methods (courses, exercises, laboratory work) and other active methods (pedagogy by project, use of new technologies, team work, internship, international mobility, etc.)
- Organization of the interventions in the curriculum by specialists from industry and business.
- Insertion within the limited time of the curriculum of experiences in the workplace and of international mobility.

Impact on the French graduate engineers

One may consider that the quality assurance and the competence approach constitute a new paradigm for the engineering education. After more than 10 years of experience, one may question its impact (see for example ref. 8) on the graduates and on the institutions; more precisely:
- What is the impact on student learning outcomes in accredited programmes and institutions?
- What is the impact on organizational and educational policies and practices that may have led to improved student learning outcomes?

It is difficult to disentangle all the sources of evolution, however after a thorough study the ABET report (2006) [8] concludes: "The weight of the accumulated evidence collected for Engineering Change indicates clearly that the implementation of the EC2000 accreditation criteria has had a positive, and sometimes substantial, impact on engineering programs, student experiences, and student learning".

In France, IESF (Association of French engineers and scientists) performs regular surveys [9] of engineers in activity, with more than 50 000 answers. In connection with CTI (Commission des Titres d'ingénieur), the graduate engineers are questioned about their opinion on the learning outcomes as defined by CTI: first, they rate their importance in their professional life, second they rate the quality of their training by their institution.

In Table 1, are reported the results for young (below 30) professional engineers in 2008 and 2012 (period during which CTI has put a strong emphasis on QA's and LO's).

The ranking by order of importance is meaningful by itself: the French young engineers estimate that professional and specialized competences are of the utmost importance as well as the "transferable skills"; however they feel as less important the societal values and the ability for research.

If one compares the two surveys, a remarkable steadiness is observed for all competences, only two vary significantly: a net increase for the competence linked to the speciality and a net decrease for the societal values. Both evolutions are coherent but somewhat surprising, since one would expect a larger awareness to environmental issues from young generations.

Table 2 shows a very significant and coherent positive evolution of the young engineers' appreciation on their training. The progress concerns all competences and particularly the integration in professional life, the capacity to work in an international context, the account of societal issues; are noticeable too the preparation to innovation and research.

Table 1.

Percentage of French engineers below 30 who consider the competence as important for their professional life (on a scale : important, fair, not important)			
	2008	2012	Changes
Awareness of societal values such as sustainable development, social relations	40 %	34 %	-6 %
Ability to innovate and to undertake research	55 %	56 %	+1 %
Ability to work in an international context	61 %	61 %	0
Capacity to account for industrial, economic and professional issues	65 %	66 %	+1 %
Knowledge and understanding of a wide field of basic sciences	65 %	64 %	-1 %
Ability to make career choices and to integrate into professional life	68 %	66 %	-2 %
Ability to mobilize knowledge in your speciality	71 %	79 %	+8 %
Command of methods and tools for the engineer	74 %	77 %	+3 %
Ability to integrate into an organization, to animate and to improve it	81 %	84 %	+3 %

ENGINEERING EDUCATION
12'2013

Table 2.

Percentage of French engineers below 30 who consider as good their initial training for the following competences (on a scale : good, fair, not good)			
	2008	2012	Changes
Awareness of societal values such as sustainable development, social relations	24 %	36 %	+12 %
Ability to innovate and to undertake research	47 %	57 %	+10 %
Ability to work in an international context	40 %	52 %	+12 %
Capacity to account for industrial, economic and professional issues	30 %	41 %	+11 %
Knowledge and understanding of a wide field of basic sciences	76 %	83 %	+7 %
Ability to make career choices and to integrate into professional life	33 %	45 %	+12 %
Ability to mobilize knowledge in your speciality	73 %	80 %	+7 %
Command of methods and tools for the engineer	66 %	75 %	+9 %
Ability to integrate into an organization, to animate and to improve it	48 %	50 %	+2 %

This evolution has to be put in correlation with CTI's policy: mandatory 28 weeks internship (with at least 14 in a company), 80% at least of the students with an international mobility (3 months or more), fluency in English certified by an external agency and the obligation to offer to each student access to a third language; obligation for the private institutions to have a significant part of their faculty involved in academic research, etc.

At least, in Table 3 are singled out the competences for which there is a large discrepancy between their importance in professional life and the quality of their training. There is a strong correlation for all but four competences: the young engineers have a very good opinion of their training in basic sciences, although they feel that it is not the most important competence they need in their profession.

Table 3.

Opinion of the French engineers below 30 about the engineer competences (2012)			
	Important for profession	Well trained	Differences
Awareness of societal values such as sustainable development, social relations	34 %	36 %	+2 %
Ability to innovate and to undertake research	56 %	57 %	+1 %
Ability to work in an international context	61 %	52 %	- 9 %
Capacity to account for industrial, economic and professional issues	66 %	41 %	-25 %
Knowledge and understanding of a wide field of basic sciences	64 %	83 %	+19 %
Ability to make career choices and to integrate into professional life	66 %	45 %	-21 %
Ability to mobilize knowledge in your speciality	79 %	80 %	+1 %
Command of methods and tools for the engineer	77 %	75 %	-2 %
Ability to integrate into an organization, to animate and to improve it	48 %	50 %	+2 %

On the contrary, they consider as unsatisfying their training to account for industrial, economic and professional issues; at a lesser degree they have the same opinion for their preparation to professional life and their training to work in an international context.

These results are taken into account by CTI in its standards and guidelines; the young engineers' dissatisfaction regarding their training to the soft skills has to be moderated, since the education has to prepare the students to their profession not to supply the employers with ready-to-use engineers. During their first years as employees, the "junior" engineers complete their training in particular in the soft skills.

But the share between which has to be trained during the studies and which is left to the junior period in the company, constitutes an open question and has to be discussed between the representatives of the institutions and of the employers.

Open questions and perspectives

During the last decade, engineering education has dramatically changed; however the process is still in midstream, institutions need a lot of efforts to durably implement the QA and LO approaches in their curricula. Many workshops are organized to discuss the details of the process which leads from the competence profile definition to the detailed study programme.

But the main open question concerns the potential gap between the intended (as described by the institution) and the achieved (by the student) learning outcomes. The faculty professors are used to assess the level of scientific and technical knowledge achieved by their students; the methodology to assess general outcomes and particularly those linked with the soft skills has to be set up and assimilated by the professors.

The European Council recently stated [10]: "the validation of learning outcomes, namely knowledge, skills and competences acquired through non-formal and informal learning can play an important role in enhancing employability and mobility...". Everyone who has been in charge of higher education has observed that during their studies, the students gain maturity, experiences in organization management, openness to social and international diversity, etc... Thus, non-formal education and informal learning are both powerful ways for an individual to gain valuable experience and skills; this fact is taken in account by the employers; during the recruitment interviews, they often spend much time discussing with the candidate about his/her activities out of the lecture rooms; for them it is a way to assess the candidate's transferable skills.

The inclusion of the non-formal education outcomes in the students' assessment is really a major issue for the next years. It has to be treated taking into account the question of the life-long learning and of "the need for more flexible learning pathways that can improve entry into and progression in the labour market, facilitate transitions between the phases of work and learning and promote the validation of non-formal and informal learning"10.

There is a general trend towards a wide diversification of the pathways to the engineer's graduation and certification; the individuals may acquire skill and competences by classical study periods, validation of professional experience, dual curricula, and online courses including the recent massive open online courses (MOOC).

As an example, in France, the law prescribes that all degrees may be delivered besides the classical academic method, either by total/partial validation of professional experiences, or by apprenticeship. More than 12 % of the 31,000 engineering master degrees awarded each year have been prepared by these alternate approaches.

The growth of apprenticeship has been very spectacular during the last years, due to governmental financial incentives and to the need to open the access of higher education. Apprenticeship combines classroom-based education and practical work experience; but at variance with many coop programmes, the work experience does not prolong the studies but is included into them (to some extent at the expense of the summer holidays). About 30% of the ECTS credits have to be assessed in the workplace by a joint team of supervisors (a professor and a professional tutor).

At which extent the same diploma can be delivered to « classical » students and to « apprentices » has been the topic of lively debates. The competence-based approach has been a powerful tool for CTI to unifying the objectives of the two pathways. In 2013, more than 100 engineering degrees are offered to students by both ways.

As a conclusion, institutions and accreditation agencies in charge of engineering education have to consider the challenge to really implement the European recommendations, based on the recent conclusions of the Conferences of European Ministers responsible for Higher Education; namely:

The member states should with a view to offering individuals the opportunity demonstrate what they have learned outside formal education and training, including mobility experiences, and to make use of that learning for their careers and further learning (...): have in place,

no later than 2018,(...) arrangements for the validation of non-formal and informal learning which enable individuals to:

- have knowledge, skills and competences which have been acquired through non-formal and informal learning validated, including, where applicable, through open educational resources;
- obtain a full qualification, or, where applicable, part qualification, on the basis of validated non-formal and informal learning experiences, (...)

REFERENCES

1. Paletschek S. The invention of Humboldt and the impact of national socialism: the German University Idea in the first half of the twentieth century // Science in the Third Reich. – Oxford: Berg, 2001. – S. 37–58.
2. Albritton Frankie P. Humboldt's unity of research and teaching: influence on the philosophy and development of U. S. higher education [Electronic resource] // Social Science Research Network (SSRN): website. – Rochester, NY: Social science electronic publ., Inc., 2013. – URL: http://ssrn.com/abstract=939811, free. – Tit.from the screen (usage date: 27.07.2013).
3. Rethinking education: investing in skills for better socio-economic outcomes [Electronic resource]: communication from the Commission to the Europ. Parliament..., Strasbourg, 20.11.2012 // European commission: site. – [S. l.], 2013. – URL: http://ec.europa.eu/education/news/rethinking_en.htm, free. – Tit. from the screen (usage date: 27.07.2013).
4. A Tuning-AHELO Conceptual Framework of expected/desired learning outcomes in engineering [Electronic resource] / OECD. – [S. l.]: OECD Publ., 2011. – 55 p. – (OECD EDU Working paper; № 60). – URL: http://dx.doi.org/10.1787/5kghtchn8mbn-en, free. – Tit. from the tit. screen (usage date: 24.07.2013).
5. Terminology of quality assurance: towards shared European values? [Electronic resource] / Fiona Crozier [et al.]. – Helinki: ENQA, 2006. – 40 p. – (Occasional papers; № 12). – URL: http://www.enqa.eu/files/terminology_v01.pdf, free. – Tit. from the tit. screen (usage date: 26.07.2013).
6. EUR-ACE® system [Electronic resource] // ENAEE : Europ. network for accreditation of eng. education: offic. site. – [S. l.]: cop. ENAEE, 2012. – URL: http://www.enaee.eu/eur-ace-system, free. – Tit. from the screen (usage date: 08.08.2013).
7. ABET [Electronic resource] // ABET: the offic. site. – Baltimore, 2011. – URL: http://www.abet.org, free. – Tit. from the screen (usage date: 20.03.2013).
8. Engineering change: a study of the impact of EC2000 [Electronic resource] // ABET: [site]. – Baltimore: ABET, cop. 2011. – URL: http://www.abet.org/engineering-change/, free. – Tit. from the tit. screen (usage date: 26.07.2013).
9. Engineers survey 2012 (in French, Enquête Ingénieurs 2012), Ingénieurs et Scientifiques de France, http://www.cnisf.org 2012. Des ingénieurs et des scientifiques de France [Electronic resource]: 23 Enquête / IESF. – Paris, 2012. – 102 p. – URL: http://www.iesf.fr/enquete//2012/resultats.pdf, free. – Tit. from the tit. screen (usage date: 26.07.2013).
10. Council recommendation of 20 December 2012 on the validation of non-formal and informal learning [Electronic resource] // Offic. J. of the EU. C 398. – 2012. – Vol. 55 (22 Dec.). – P. 1–5. – URL: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2012:398:0001:0005:EN:PDF, free. – Tit. from the tit. screen (usage date: 24.07.2013).
11. Bourdoncle R. Qu'est-ce qu'une formation professionnelle universitaire? / Raymond Bourdoncle, Claude Lessard // Rev. fr. de pédagogie. – 2003. – Vol. 142. – P. 131–181.