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METROLOGY EDUCATION IN THE CURRICULUM OF THE ACCREDITED BACHELOR IN ENGINEERING PROGRAMME OF THE "VRIJE UNIVERSITEIT BRUSSEL"

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Abstract − The Bologna process has induced an important change in the curricula building of the university bachelor and master programmes towards a sustainable, transparent and quality driven European education system. In Belgium, engineering education has completely been revised. The transformation of the former system, leading to the degree of academic engineer after 5 years of study, into the typical Bologna 3+2 structure leading to the academic degrees of respectively Bachelor in Engineering and Master in Engineering has created opportunities to completely reconsider and restructure the Engineering education at the Vrije Universiteit Brussel. One of the main objectives of the new programme has been to meet the requirements with respect to the education output contained in the "Dublin descriptors" and that of present-day society at large. In this paper we will report on the experience in this transformation and we will focus on lecturing metrology in the bachelor of engineering programme in particular.

Keywords: Curriculum development, education in metrology, engineering skills and competences.

1. INTRODUCTION

The "Vrije Universiteit Brussel", the second largest university of Brussels, is in its Constitution (Art. 1 and 3) committed to the development, transfer and application of high-ranked education and research to contribute to the progress of humanity. This implies that the VUB is continuously aiming at anticipating on what is happening in the world in order to provide it with human resources educated to contribute to its economic growth and the development of a knowledge based society. Hereto, international academic and professional contacts are indispensable. As one of the leading universities of the capital of Europe and member of the UNICA (network of the UNIversities of the CApitals of Europe) [1] and T.I.M.E. network (Top Industrial Managers for Europe) [2], the VUB aims to create and provide an international atmosphere on the campuses by encouraging high density exchange of students in the education programmes and by attracting foreign researchers and guest lecturers.

The Bologna declaration has triggered an important change in Europe in the way of organising academic engineering education towards a sustainable future. In Belgium, as has been the case in many other European countries, engineering education had to be completely reconsidered and revised.

The former engineering education system in Belgium, was based on the system provided by the French "Écoles Polytechniques" [3], [4]. The Polytechnic School (École Polytechnique) of the "Université Libre de Bruxelles" (ULB [7], Free University of Brussels) was founded in 1873 and was entitled to offer the legal diploma of "Ingénieur civil des Mines " (Mining Engineer) and "Ingénieur civil des Constructions" (Civil Engineering) after 5 years study. In 1890 the name was changed into "Faculté des Sciences Appliquées" ("Faculty of Applied Sciences") and the school became a Faculty of the University. In the course of the twentieth century, the list of academic legally recognised grades was enlarged: "Ingénieur civil Mécanicien et Électricien" (Mechanical and Electrical Engineer in 1929), "Ingénieur civil Chimistes" (Chemical Engineer in 1958) and "Ingénieur civil Métallurgiste" (Metallurgic Engineer in 1962). All degrees could be obtained after a minimum of 5 years of academic study. The Belgian academic engineering studies showed close similarities with the French system operational in the "Écoles polytechniques universitaires" (Polytechnic university schools) and the Dutch "Technische Universiteit" (Technical Universities) until 1986.

The transformation of the former system, leading after 5 years of study to the academic degree of engineer into the academic Bachelor in Engineering and Master in Engineering according to the Bologna agenda has been studied carefully at the VUB and has forced the authorities to completely reconsider the education system in order to satisfy the output required by the so-called "Dublin descriptors" [5]. The first reactions of the members of the Faculty of Engineering of the VUB active in the boards competent with educational matters were not very enthusiastic at all. Belgian engineers have an excellent (international) reputation and it was not clear what could be the benefits of a reform. Many feared that the consequence of the implementation of the Bologna declarations would be to level down the standard of the engineering degrees. Soon it was realised that the need of new structures was offering a unique opportunity to match the outcomes of the education to the new needs of present society and to attract new type

of students. It was decided, therefore, to focus on those issues which would turn the reforms into benefits.

The transformation of the engineering education at the VUB has been based first on a critical analysis of the requirements of the new Bachelor-Master structure, as was imposed by law in the Flemish and French Communities in Belgium. But it was based also on consultation with alumni using polling surveys, self assessments including S.W.O.T. analysis and assessments by the education authorities (VLIR-VLOA Flemish – Dutch inspection commissions) held in 2004 and 2007. In the coming sections, the experience gained in the process of realising these drastic fundamental modifications of the Engineering curriculum of the VUB, will be shared and, in particular, attention will be paid to the introduction of metrology and measurement science education in the curricula of the offered bachelor of engineering programmes.

2. OBJECTIVES OF THE BACHELOR IN ENGINEERING EDUCATION PROGRAMME OF THE VUB

The general objectives, aimed final qualification terms and the vision regarding the education of the current VUB program of Bachelor in Engineering are partly based on the previously operational two year candidature system, but have been fundamentally transformed for the current Bachelor-Master degrees. In particular, attention was paid to the introduction of the educational vision of the VUB authority, which focuses on competence acquisitions, and with the recommendations expressed by the VLIR-VLOA assessment commission of 2004. Compared to the objectives of the former Candidature – Civil Engineer (ir.) programs, those of the Bachelor-Master have been targeted more intensively towards the development of critical reflections regarding the acquired competences, towards skills and attitudes necessary to grow towards the profession of an academic engineer, towards research competences, management techniques and presentation and discussion skills.

The academic engineering education at the university aims at the formation of young persons to contribute efficiently to the design, realisation and support of sustainable projects with a scientific and/or technological content for the benefit of the fast evolving modern society. The bachelor education program, therefore, has the aspiration to train the students to become critical, conscious and engaged engineer scientists in a spirit of liberal examination from a non-dogmatic and pluralistic vision towards society and the chosen engineering specialisation field, with emphasis on the sustainability of the solutions, ethics and awareness of the implications to the environment.

This implies that a student should be able to follow an academic educational program that attempts to:

- Ensure a general, broad and in depth basic education, where emphasis is not put to overspecialisation;
- Provide a close relationship with and feedback from scientific research and the industrial field of the profession;
- Make the students acquire not only scientific perceptions, but also a broad scientific culture with accents on autonomy, creativity and inventiveness.

Moreover, the educational program encourages the development of attitudes that will enable future engineers to take responsibilities in a team and to reflect about the impact of their work. Social and language abilities, particularly for international literature investigations and autonomous assignments, therefore, should be encouraged. Likewise, one can state that an academically formed engineer:

- In addition to solving purely technological questions, should be able to delimit and formulate his tasks in order to submit these to a critical examination and the check the solutions for their sustainability and social relevance;
- Should apply oneself to a simultaneous horizontal broadening and vertical deepening of his discipline within a continuously changing society and industrial context, in a multi disciplinary and international environment. Life-long-learning has become an indispensable component in the life of an engineer.

An elaborated list of the aims and end terms (acquired competences) of the bachelor in engineering programs of the VUB is available from the faculty website [6]. They can be summarised as follows:

- To ensure that students have acquired general and scientific competences which characterise academic education;
- To supply the common fundamental knowledge, skills, attitudes and ethical concerns, which are peculiar for the profession of an engineer;
- To enable future masters in engineering to choose their additional specialisation adequately by developing systematic knowledge of the kernel elements of the different disciplines of the profession of an engineer, including discussions about the most recent developments in these fields;
- To provide the specific foreground knowledge required to continue the studies in a specific master in engineering program in the home country and/or abroad;
- To present the basis for life-long-learning.

3. IMPLEMENTATION OF THE BACHELOR IN ENGINEERING PROGRAMME AT THE VUB

The bachelor programme is accessible to all students having finished their secondary school. At the end of the bachelor studies students should possess a broad basis of skills and knowledge for their continuation in an engineering master programme. The programme is structured such that milestones in the development of competences can be defined after each semester of the Bachelor education. They are summarised below [8]:

First semester:

In general, the first semester starts on the last week of September and accounts 13 weeks. In the courses “Engineering skills” and “Informatics with programming project” the basic competences that every engineer should possess are instructed. These are:

• "Mathematical calculus": series, derivatives, integrals en elementary differential equations, which are regarded as the basic tools for courses in physics, chemistry and mechanics;
• "Measuring and experimenting": measurement set-up and instrumentation, metrology, scales and units, calibration and uncertainties of measurements, modelling and measurement errors;
• "Communication skills": written and oral professional reporting;
• "Computer competences": text processing, PowerPoint presentations, spreadsheets, queries on the internet, email communication, design of a website;
• "Programming": theoretical analysis of problems, structuring, algorithms, and practical implementations.

In addition to these engineering skills, courses in basic and natural sciences are started. In the middle of the first semester the students are tested on the acquired engineering competences. For the units in basic and natural sciences both theoretical and exercises examinations are scheduled in January.

Second semester:

In the second semester the following competences are instructed:
• "Mathematical computer techniques": programming in Matlab;
• "Chemical experimenting": including the application of measurement theory, metrology and engineering skills studied in the first semester.

The acquisition of theoretical and experimental knowledge is continued for the field of mathematical analysis, basic and natural sciences. Using the formats of seminars, invited lectures and practical assignments, the students also gain insight in issues regarding the environment in the profession of an engineer. The students are tested on the levels of knowledge, communication skills and logical reasoning.

Third semester:

The advancement of theoretical and experimental knowledge and insight in the basic education units, including technical drawing on a computer, is continued.

In the course of "Applied electricity", an introduction to system theory (linear systems, 2-port devices, transfer function) is given followed by basic electrical measurement theory. In the latter, sensor-transducer principles are illustrated as well as the energy conversion principle that provides measurements of the physical quantity of the measurand after electrical signal conditioning and processing (filtering, amplifying, scaling, conversion …). Practical work in the laboratory in small groups (up to 5 students) stimulates the skills of experimenting, team work and scientific reporting.

Students are tested on knowledge and reasoning skills.

Fourth semester:

The students have the opportunity to validate to a large extent the acquired knowledge via a technology project. For each of the 4 engineering specialisations that are offered (construction engineering, electro-mechanical engineering, electronic and information technology engineering and chemical and material engineering), a technology project is organised in training workshops, and hence, all students participate to 4 engineering projects. Added values are: team work, planning and organisation, self-study, learning or improving of scientific English and communication. The technique enabling acquisition of knowledge from practical experiences is introduced, as the basis of life-long learning. The students learn to gain theoretical knowledge from a practical assignment. Students are judged on the combination of functioning in a team, the application of existing knowledge and the acquisition of new knowledge resulting from problem-oriented working, communication and reporting.

Fifth and sixth semester:

In the third year of the bachelor studies (semesters 5 and 6), the students choose a specialisation. The technology workshops in the fourth semester guide the students in an optimal way in that choice. The choice will enable the students to continue their studies in a master in engineering programme after having obtained the diploma of Bachelor in Engineering.

4. METROLOGY EDUCATION IN THE BACHELOR IN ENGINEERING PROGRAMME AT THE VUB

The broad education basis, common to all final specialisations in engineering that are offered at the Vrije Universiteit Brussel in the four first semesters, allows to ensure that many engineering skills can be approached in a multi disciplinary way. This is e.g. the case for "Communication skills", "Computer competences", "Environmental Aspects of Engineering", but also with respect to "Measuring and experimenting".

The approach in teaching measurement science and metrology in the bachelor of engineering programme of the VUB has been inspired by the progress in research in the field of measurement theory, in large extend provided by the IMEKO Technical Committee 7 since the early nineteen eighties. The very fruitful contributions and numerous papers provided by IMEKO TC7 (and TC1) members, such as L. Finkelstein, P. Stein, D. Hofmann, E. Woschni, R. Morawski, L. Mari and many others have led to the recognition that the term "measurement theory" for the broad measurement and instrumentation activities worldwide has been replaced by "measurement science" (in the early nineties) and to the observation that measurements are part of a complex estimation scheme.

Therefore, in the introduction of measurement science in the course on engineering skills, emphasis is laid first on the modelling and identification aspects in the basic theory of measurements. Secondly, measurement errors are investigated and methods to derive the uncertainties of the measurements are proposed. This is achieved by a general introduction to metrology, where traceability issues are put forward.

The contents of the courses where the discussed measurement science and metrology methods are introduced are treated shortly further.

In the first semester, students receive a first introduction in measurement science and metrology in the course "Engineering Skills", which has three main parts:
• Mathematical techniques in engineering;

• Professional communication, reporting and presentation;
• Measuring and experimenting.

The course "Measuring and experimenting" helps engineering students to build up experimental research skills. This includes judiciously planning and performing an experiment, correctly gathering and analyzing the data, and drawing and reporting the conclusions in a proper scientific way. Hands-on experience with basic instruments such as e.g. callipers, a goniometer, a microscope, a multimeter (V, I, R, C, L), potentiometers, (digital) oscilloscopes, and a variety of sensors, are gained in the accompanying laboratory course. A study guide, which covers both the lectures and the laboratory work, help the student to achieve these objectives. The study guide also fulfils the need for self-training and self-evaluation.

In the third semester, in the course "Applied Electricity" the students have 14 hours lecture (from the 42 hours of this course) dedicated to metrology and the theory of measurements, followed by 6 practical sessions in the laboratory of half a day experimenting each. The content, skills and set-up of the experiments will be presented next and it will be shown that the structure of the set-up of the Technical Committees within IMEKO [9], [10] enables the education in metrology in focussing on the main topics, problems and novel realisations in the metrology related to work undertaken by academic institutions, research institutes and National Metrology Organisations. The structure and mission of BIPM is introduced, as well as the GUM [11].

The 6 practical sessions on electrical measurements are:

- Electrical power measurements based on Watt-meters for 50 Hz, 220 V consumer electrical power;
- Measurement of impedances using bridges;
- Accurate measurement of very low resistances using a double bridge (Kelvin bridge);
- Study of an operational amplifier used as amplifier, differential amplifier, buffer and integrator/ differentiator;
- Study of sensors (strain gauge, pressure, temperature, electric/magnetic field, magnetic fluxes);
- Precise measurements of DC voltages using potentiometers.

Since the students choose their specialisation field only from the fifth semester, in this course electrical measurements are studied that offer useful applications in all fields of engineering. The electrical power consumed by in house light bulbs are measured using the main 220V – 50 Hz power system available in Belgium (active, reactive, $\cos(\varphi)$), which will be of importance for future electro-mechanical engineering students. Impedance and low voltage measurements are important for future chemical and material engineering students, whereas several sensors are chosen in the field of construction engineering. The operational amplifier is modelled as an ideal two port system. It is also the first electronic component with which the students gain insight in electronics and discover the difference between the ideal model and the measured SISO (single input – single output) system. Other studied set-ups keep up the broad interest for all engineering fields. Obviously, all laboratory topics in this practical work show their direct importance also to future students in electronic and information technology engineering, since they all are based on electric and electronic theories and applications.

The competences acquired for the experiments in the laboratory are highly appreciated by the students when starting to undertake the practical technology projects starting the semester thereafter (fourth semester).

In the course of the academic year 2008-2009 the board of the faculty of engineering has set-up a commission, under presidency of the author being also the chairman of the educational council for the bachelor in engineering programs (in Dutch, the ORBA: Opleidingsraad Bachelor), to revise and update the content of the chapter 'measurement science and metrology' in the course "Engineering skills" in the first semester. Since the impact of modern metrology, which manifestly originated from the research in measurement of electrical quantities (e.g. IMEKO TC4), mechanical quantities (e.g. IMEKO TC3 for mass, force, torque, TC5 for hardness, TC9 for flow measurements), thermal properties (e.g. in IMEKO TC12), also gains importance in chemical engineering (e.g. IMEKO TC24), in nutrition (e.g IMEKO TC 23) and environmental measurements (e.g. IMEKO TC19), it is proposed to illustrate better to the students the role of metrology in industrial activities, production and trading. Four new practical laboratory set-ups are currently under investigation and preparation; one for each field of specialisation in engineering at the VUB (electronics and information technology, electro-mechanical, chemical and material and construction engineering).

5. CONCLUSIONS

As a general conclusion on the education of metrology and measurement science and theory in the bachelor in engineering programmes of the Vrije Universiteit Brussel, one can state that the transformation of the engineering education from the Bologna declarations were used in an efficient way to propose to the students an attractive well balanced but broad study program. From experience gained from IMEKO activities by the Technical Committees (conferences, symposia, workshops) and the World Congresses, the new bachelor in engineering programme has adequately introduced modern metrology in the frame of measurement science, which should offer the students a sound basis for further continuing studies in a master programme, research (e.g. PhD), and hence, for their future career in human society.

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