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Engineering Education in the US and the EU

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Chapter 5

Engineering Education in the US and the EU

Louis L. Bucciarelli, Eugene Coyle, Denis McGrath

Abstract: Systems for the education of engineers in the US and the EU differ in significant ways. In this chapter we describe and reflect upon differences in accreditation policies and procedures, curriculum structure and content, admissions criteria and student mobility. Within the US there is a surprising uniformity among both private and public university programmes in engineering education, due in large part to the acceptance of ABET's (Accreditation Board for Engineering and Technology) authority in setting standards for curriculum content. Within the EU there is greater programme variety, although some degree of harmonization is in the works due to the Bologna Declaration. We describe and analyze current efforts in Europe aimed at establishing a pan-EU authority for accreditation - the EUR- ACE Framework. One topic in curriculum structure draws our attention - the perceived value of liberal studies in engineering and the potential for significant reform of the engineering curriculum in this regard. Criteria for admission to university study in engineering differ among the different members of the EU. In the US, criteria are more or less the same whether the student applies to MIT or the University of Michigan. Understanding these differences is essential if transatlantic cooperation in higher (and vocational) education is to be achieved as is the intent of a new EU-US programme - The Atlantis Programme (2006-20013).

Key words: Programme accreditation, ABET, Bologna Declaration, EUR-ACE, Atlantis

Engineering Education in the EU

A brief history

The first moves towards the formal education of engineers began with the establishment in France of the *Ecole des Ponts et Chaussées* in 1747. Students were essentially state employees, their professors 'savants' and engineers of the 'corps'. Much of their learning was based on actual engineering projects. Their summers were spent in 'stages'. As outlined by Dooze, at the time of the French Revolution, the standards of this school

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were markedly increased and to the present day it is one of the leading grandes Ecoles in France (Dooge, 2006). The *Ecole des Mines*, established in 1783, another grande ecole, emphasized the sciences; practical training was again via stages in the field. In 1794, Monge was instrumental in setting up the *Ecole de Travaux Public* which the next year was replaced by the *Ecole Polytechnique*, a school dedicated to providing a high intellectual and scientific formation to its students through a curriculum of prescribed courses showing a strong mathematical bias. Entrance was highly competitive via a common examination - on the order of 100 students were admitted. This remains the case today.

The *Ecole Centrale des Arts et Manufactures* (1829), offered an education more inclined toward industrial practice - stages again a requirement - and the content of its courses were a bit less abstract. We shall see how these French institutions provided a model for early engineering education in the US. All of them were established independent of the nation's university system. Their main concern, according to Wickenden, was "...only with preparing a limited 'corps d'élite' of bureau chiefs and directors of industry while the training of subalterns was largely neglected" (Wickenden, 1929).

The more ordinary citizen was not totally neglected: The *Conservatoire des Arts et Métiers*, established like the *Ecole Polytechnique* by an act of the Convention in 1794, had other aims than the grandes ecoles. Its purpose was to spread technical knowledge among the less well educated - ordinary workers and the like. Its collection of technological objects and museum presentations of science provided materials for the explanation useful to those in industry, arts and crafts. (Sebestik, 1986)

In Britain in 1812, a special Royal Engineering School was set up at Chatham as a result of the experience in the Peninsular War that revealed the importance to the outcome of the war, of fortifications. As early as 1796, some lectures on the principles of engineering were given in the University of Cambridge. But for most of the 18th, and well into the 19th century, the education and training of those responsible for the building of bridges and railroads, the improvement of the engines and machinery of the industrial revolution, were schooled by a system of apprenticeship and through 'pupilage'. The aspiring engineer studied as an intern with a mentor, an already established and practicing engineer. Their internship lasted for three or four years and might cost on the order of 1000 pounds. (That's what Brunel charged). (Buchanan, 1986)

In 1841 the first professor of Civil Engineering, Irish-born Charles Vignoles was appointed in the University of London (Doodge, 2006). It was only in the latter half of the 19th century that engineering was seen as based on the sciences and programmes developed out of the pursuit of science in institutions of higher learning. Those who worked toward this end found it a challenging task: "*The obstacle against which they had to contend was not*

so much the pupilage system as an attitude of distrust toward scientific methods. The pioneer professors ...were sometimes referred to in mild contempt as 'hypothetical engineers' (Wickenden, 1929). It was the practical that was of interest. Sir Benjamin Baker, a president of the Institute of Civil Engineers, in 1895 warned "...technical education is of little value unless accompanied by practical experience, sound judgement, and bold initiative, which rather than book knowledge, characterized the famous members of this institution in the past".

In Ireland, the first Professor of the Practice of Engineering, John MacNeill, was appointed in Trinity College, Dublin in 1842. (Dooge, 2006) Engineering education in Italy commenced when, in 1786, a note from the royal imperial assembly of government decreed that "*those that want to practice the profession of Engineer or Architect must study in the University of Pavia*" (Erba, 2005).

In the UK, by the end of the nineteenth century the Institution of Civil Engineers was setting its own examinations for the qualified membership grade of the Institution. The other institutions soon followed suit. It was, therefore, possible for a person to obtain professional membership without a University degree. Indeed University degree programmes had to be recognised for exemption from the Institutions examinations so the institutions examination was the bench mark for standards even though few persons sat the examination. This was primarily because there was an alternative route in the publicly financed state technical college sector. In 1921 the Ministry of Education established a system of national certificates and diplomas to "enable capable and ambitious young workers to break through into the higher ranks of industry". They would enable students in technical colleges to undertake work of a high standard, they would provide technical colleges with a flexible system of examining, and provide industry with a well trained body of technicians and professional men. The scheme was administered by the Ministry together with the relevant professional institution so the institutions were involved in examining in this system.

This route supplied more engineers than the universities in between the two world wars and in the post-war period into the late nineteen sixties. In 1957, only a third of those admitted to professional membership of the engineering institutions possessed university degrees the remainder had alternative equivalent qualifications.

The institutions lay great store in the possession of a Royal Charter. Both the Institution of Production Engineers and the British Institution of Radio Engineers had to fight against vested interests to get their

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Royal Charters in the 1960's. Early in the 1960's the professional engineering institutions formed a Council of Engineering Institutions and obtained a Royal Charter for it (Now the Engineering Council).

The University of Karlsruhe was formed as a Polytechnische Schule (polytechnical school) in October 1825, having as an example the Ecole Polytechnique in Paris. As such, it was the first Technical University or Technische Hochschule (TH) in Germany. However, the Technical University of Freiberg originated in a mining academy in 1765 (University of Karlsruhe, 2008).

Curriculum structure and requirements

The duration and structure of engineering programmes in continental Europe are based on a relatively long programme of studies of four to five years in duration and firmly grounded in mathematics and the sciences. In France, for example, students wishing to pursue a degree in engineering must complete two years (or three) in “classes préparatoires” before gaining entry into a three year degree (“licence”) programme at one of the Grandes Ecoles. A further requirement in Germany, Austria and Switzerland was the integration into the curriculum of a period of approximately 12 months in practice in industry, together with project work in the research units of universities. A “stage” in industry or R&D laboratory is also a requirement of many engineering schools in France.

We take as an example, that of the Ecole Centrale de Nantes (Ecole Centrale de Nantes, 2008) - which leads to the award of a “Diplôme d'ingénieur certifié CTI”, a programme of three years duration. Admission can be by several different routes but the great majority (over 80%) take the “concours central supélec”, an exam given nation-wide, originally established for those seeking entry to the Ecole Supérieur d'Electricité”. Two hundred and sixty five (265) places at Nantes are reserved for students who, in competition with their peers, take this exam.

As is the case for all Grandes Ecoles, students spend the two years intervening between when the student has completed his or her studies (and examinations) for the BAC, what in the US would be called a high school diploma, in “classes préparatoires” - an intense period of study at a “lycée” in mathematics and physics (roughly 75% of the time), philosophy, foreign languages, and, via electives, study in engineering science, chemistry, and computer science.

The students follow a common programme the first two years of the three year programme at Nantes. In the first three semesters the students study mathematics and the fundamental sciences, the engineering sciences (e.g. mechanics of continuous and discrete media, thermofluids, signals and systems, instrumentation, vibrations), industrial management, and continue their language learning. In the fourth semester, students have some elective

freedom and can begin to specialize. In their third year they choose both an “option disciplinaire” (systems engineering, IT, industrial product and system development, materials, simulation in mechanics, civil and environmental engineering, hydrodynamics and ocean engineering, energy) and an “option professionnelle” (Finance, Entrepreneurship, Industrial design, Marketing and innovation, Project management, Quality, R and D, Sustainable cities and services,. Students are also required to do a summer “stage” in industry and a “Travail de Fin d'Etudes”. The latter requires a research and development stint in an industrial laboratory, a research laboratory, or in an international laboratory.

Students may choose to continue at Nantes and obtain a master's degree in, for example, applied mechanics, automation and production systems, science and technology of the urban environment. There are other degree programmes leading to other degrees, including double degree programmes in management and engineering, architecture and engineering. Ecole Centrale de Nantes has structured its programmes so as to accommodate foreign students, in line with the Bologna recommendations.

In the UK, which included Ireland until 1921, the programmes were originally generally of three years duration. The structure in the UK has evolved into a four-year Master degree programme or a three-year Bachelor degree leading to a one-year Master programme, as the educational standard for the professional engineer.

We take as an example, the course in Mechanical Engineering at the University of Manchester where a student may work toward a 3 year BEng degree or a 4 year MEng degree. There are options for students of management, and for others aiming to study abroad.

To be admitted to the University, an applicant must have studied at least three A-level subjects, including Mathematics and a science (Physics preferred but Chemistry, Biology or Engineering Science also acceptable), and received grades of A, B, and B upon examination. Students choose their A-level subjects upon passing the General Certificate of Secondary Education (GCSE) exams in a number of subjects usually by the age of 16. Two years of A-level study, for many at a ‘sixth form college’, culminate with examination usually by the age of 18. There is a special Bachelor’s programme “Engineering with a Foundation Year” (4 or 5 years) which includes a year of preparation for students who have backgrounds different from the norm, e.g., older students, applicants lacking in the prerequisite A-levels. Total undergraduate population at the university is between 25 and 30 thousand - the biggest single-site university in the UK. Tuition and fees for a citizen of the UK or the EU is on the order of £3,000 sterling. A non-European (foreign) student pays about three times that amount.

The curriculum includes a common first year of study for students in the School of Mechanical, Aerospace, and Civil Engineering. Students together study mechanics, thermo-fluids, materials, mechatronics, communications,

design and mathematics. The school highlights its innovative teaching method called Enquiry Based Learning (EBL) *“In this environment you will work in small groups, supported by a member of staff, to analyse and solve a wide range of problems and challenges. You will need to think creatively, carry out personal research and work as a team.”*(MACE, 2008).

In the second year, students not only continue on in the engineering sciences but spend time in engineering design, in professional studies and in management. The course literature stresses an ‘innovative application-driven environment’. In the third year, the student can specialize in their choice of courses - machine tools, management, manufacturing, materials, processes, mathematics, micro-mechanics, modelling & simulation, plant monitoring, power plant, environment, and others. They also must engage in an individual project under the guidance of a member of the academic staff.

In Ireland, a four-year Bachelor degree has been in place for nearly 50 years. Taught Master degree programmes have been offered for over a decade (from the mid nineteen nineties) at several universities, including Dublin City University, Dublin Institute of Technology, Trinity College Dublin and the University of Limerick. In 2004 the first Master degree programme, based on a 3+2 (Bologna) structure commenced. Further Master degree programmes commenced in 2006 and it is expected that this structure will become the norm within the next five years.

The total formation of the professional or Chartered Engineer in the UK and Ireland is deemed to require, in addition to completion of an accredited engineering degree programme, a number (normally a minimum of four) of years working in industry, developing a range of professional engineering competencies which are then tested through a professional review process.

The Bologna Declaration

In June 1999 the Bologna Declaration (Bologna, 1999) was published. To date it has been signed by 45 national governments. Its overall objective is the establishment of a European area of higher education in which student mobility would be facilitated and enabled. A further objective was to increase the international competitiveness of the European system of higher education in attracting overseas students. The section of the Declaration relevant to accreditation is that which states that higher education in Europe should be structured in two main cycles where access to the second cycle shall require successful completion of first cycle studies, lasting a minimum of three years. The degree awarded after the first cycle *“shall also be relevant to the European labour market as an appropriate level of qualification. The second cycle should lead to the master and/or doctorate degree as in many European countries.”*

Shortly after the publication of the Bologna Declaration, the main European consortia involved with engineering education began to discuss the

implications of the two-cycle degree structure. The Declaration is being widely interpreted and applied so that a significantly large majority of universities and colleges are applying the new structure to their engineering programmes. However, there has been little dialogue between national governments on the different ways of interpreting and implementing the postulates of the Bologna Declaration in their home education systems. This has given rise to difficulties in some European countries where changes to engineering education structures lie within the remit of the relevant ministry of education. In certain cases, questions about new structures and funding of these new structures remain open.

The position of the European engineering community is best described in the CESAER/SEFI Communication “Engineering Education and Research and the Bologna Process – On the Road to Bergen 2005” (Bologna, 1999).

2. Bachelor/Master Studies in Science and Engineering

2.1. The 3+2 model has become a standard reference in engineering. This should not exclude other possible paths towards the second-level degree as an integrated 5 years curriculum or a 4+2 scheme or a 4+1 model.

2.2. Engineering needs at least two types of first-level degrees, each with clearly defined aims and objectives. First cycle degrees should be a gateway to a wide choice of second cycle programmes. The receiving institutions have the freedom to define criteria and procedures for the selection of students for the second level degree courses.

Typically, the new structure accommodates two different career paths: i) Three-year programme leading to a Bachelor degree in *engineering science*, the primary purpose of which is preparation for a two-year programme in engineering (science) leading to the degree of Master of Engineering, in any European university. The Bachelor degree is generally deemed a “mobility hub” rather than a qualification for immediate use in the work place. It should be noted that in some countries there are internal disagreements between universities, accreditation agencies and industry on whether or not such Bachelor degree graduates are employable in engineering roles. ii) Three-year programme leading to a Bachelor degree in *engineering technology* leading to immediate employment as an engineering technologist. Normally, universities offering 2-year Master degrees in engineering will require such Bachelor degree in engineering technology graduates to successfully complete a programme of additional studies before admitting them to the Master degree programme¹.

¹ In Germany, Universities of Applied Science offer two-year Master degree programmes tailored to enable such Bachelor degree graduates to be admitted directly to a Master degree without a requirement for any additional studies

Accreditation institutional development

Quality assurance of engineering education in most European countries is carried out on a faculty or university-wide basis, sometimes on the basis of state legislation. In the UK it is carried out under licence from the Engineering Council, by professional bodies such as the Institution of Engineering and Technology, and in Ireland by Engineers Ireland (EI) under “The Institution of Civil Engineers of Ireland”. The Charter Amendment Act of 1969 empowered Engineers Ireland to establish the standard required to become a Chartered Engineer in Ireland. Regions, Divisions and Societies within EI include all of the primary engineering disciplines, including electrical and electronic, mechanical and manufacturing, chemical and process, civil, agriculture and food, biomedical, energy and environment, ICT, road and transport and health and safety.

The felt need to accredit programmes is a relatively recent development in Europe, dating from 1983 in the UK and Ireland. In France, although the Commission des Titres d’Ingénieurs (CTI) was established in 1934, it was not until 2007 that this organization developed policies and procedures to carry out programme-based accreditation of engineering education. In Germany, the Fachakkreditierungsagentur für Studiengänge der Ingenieurwissenschaften, der Informatik, der Naturwissenschaften und der Mathematik e.V. (ASIIN) was authorized to carry out accreditation of programmes in engineering, science and mathematics by the German Accreditation Council in 2002. The Russian Association for Engineering Education (RAEE) through its Accreditation Centre has been accrediting engineering education programmes since 1992. The Portuguese Order of Engineers (Ordem dos Engenheiros) became involved in programme-based accreditation in 2008.

For a number of years, the European engineering community, primarily under the auspices of the Fédération Européenne d’Associations Nationales d’Ingénieurs (FEANI) has been considering the possibility of developing an instrument to enable the mutual recognition of professional engineering degree programmes which would operate in a manner similar to the Washington Accord:

“The Washington Accord, signed in 1989, is an international agreement among bodies responsible for accrediting engineering degree programmes. It recognizes the substantial equivalency of programmes accredited by those bodies and recommends that graduates of programmes accredited by any of the signatory bodies be recognized by the other bodies as having met the academic requirements for entry to the practice of engineering.” (Washington Accord, 1989)

Standards would be set, which accreditation agencies would have to meet, if they were to be included. Under the auspices of FEANI (Fédération Européenne d'Associations Nationales d'Ingénieur), a group of individuals representing European engineering professional bodies was brought together to form the European Standing Observatory for the Education of Professional Engineers (ESOEPE). ESOEPE submitted a proposal to set up the European Accredited Engineer (EUR-ACE) project with the objectives of

- ensuring consistency between existing national engineering accreditation systems,
- establishing a European “quality label” for accredited programmes,
- assisting with the establishment of accreditation in European countries where it does not yet exist,

thus improving the quality of engineering education, facilitating transnational recognition and mobility of graduate engineers.

In September 2004, the European Commission supported the EUR-ACE project with funding of 0.5 million euros. The partners in the project were made up of six European engineering associations/networks and eight national associations active in accreditation of engineering programmes. The six associations/networks were FEANI (contracting partner), SEFI, CESAER, EUROCADRES, ENQHEEI, UNIFI/GREE and CLAIU-EU. The eight national associations active in accreditation were ASIIN (Germany), CTI (France), EC(UK), Engineers Ireland, COPI (Italy), OE (Portugal), UAICR (Romania) and RAEE (Russia).

On 7th October 2005, most of the EUR-ACE partners, together with a number of new engineering associations, decided to establish ENAEE as a “Not-for-Profit International Association” under Belgian law. The founding members adopted statutes on 8th February 2006. ESOEPE dissolved itself on 30th March 2006.

Article S5 of the statutes cites the purposes of ENAEE in general

“to build confidence in systems of accreditation of engineering degree programmes within Europe and to promote the implementation of accreditation practice for engineering education systems in Europe...in particular.....participating in the creation and ultimately the administration of a European accreditation framework for engineering education programmes” (Our translation from French).

Funding was secured from the EU for the start-up of ENAEE. Fees to be paid by accreditation agencies seeking the authorisation to disseminate the EUR-ACE label supplemented this. In future, ENAEE will need to be self-funding on the basis of incoming fees.

At a General Assembly meeting held in Brussels on 30th March 2006, an Administrative Council was elected. It was also decided that the EUR-ACE acronym should be used to describe the quality mark to be known as the “EUR-ACE Label”. The “EUR-ACE Label Committee” has responsibility for establishing policies and procedures whereby accreditation agencies in Europe will be authorised to add the EUR-ACE label to their accreditations.

Accreditation process, criteria, and guidelines

The criteria used by EUR-ACE in the project were:

- Accreditation would be the result of a process certifying the suitability of an engineering programme as an entry route to the profession.
- Would involve periodic assessment against accepted standards.
- Would involve peer review of written and oral information by trained and independent panels, including academics and professionals.
- Accreditation will be only of each engineering programme and not of a department or university.
- Accreditation will be only of the engineering programme and not of the full formation of the registered professional engineer.

The EUR-ACE partners completed the project in October 2005. In implementing the project a series of meetings were held in Brussels and other European cities. The EUR-ACE partners published a set of documents at a workshop hosted by the European Commission on 31st March 2006. The documents included a framework of standards for the accreditation of engineering programmes (with template and commentary); a proposal for the organization and management of the EUR-ACE Accreditation System; a financial plan; an overview of accreditation procedures and criteria; and a report on trial accreditations. (These are available on www.enaee.eu).

The first of these documents established accreditation criteria for first cycle (Bachelor) and second cycle (Master) degree programmes in line with the Bologna Declaration. An agency that employed these established criteria - and deemed to have done so after the fact - would be authorised to attach the EUR-ACE “label” as a quality mark on all its accreditation decisions. Thus, the graduates of all engineering degree programmes with the EUR-ACE label would be, at some future date, recognised by all other accreditation agencies authorised to issue the EUR-ACE label, in a similar “modus operandi” to the Washington Accord.

Engineering programme outcomes were grouped under the following six headings:

- Knowledge and Understanding
- Engineering Analysis
- Engineering Design
- Investigations
- Engineering Practice
- Transferable Skills

All six headings are used for both first and second cycle programmes though there are significant differences in the requirements at the two levels, particularly in relation to the first three headings. Students entering an accredited second cycle programme will normally have graduated from first cycle programmes but universities should provide opportunities for students with a similar engineering qualification, though not accredited, to be admitted to the second cycle programme.

Guidelines are also provided on how an engineering programme for accreditation should be described. These include,

- Programme educational objectives consistent with the mission of the higher education institution and the needs of all interested parties (such as students, industry, engineering associations, etc.) and programme outcomes consistent with the programme education objectives and the programme outcomes for accreditation;
- A curriculum and related processes which ensure achievement of the programme outcomes;
- Academic and support staff, facilities, financial resources and cooperation agreements with industry, research institutions and other Higher Education Institutions adequate to accomplish the programme outcomes;
- Appropriate forms of assessment which attest the achievement of the programme outcomes;
- A management system able to ensure the systematic achievement of the programme outcomes and the continual improvement of the programme.

Further Guidelines have been published on action to follow the outcome of the accreditation process, the decision and the agenda to be followed on the visit to the college.

Engineering Education in the US

While the urge to change engineering education has always been a prominent feature in the development of college and university programmes in the US over the past century, today's need for renovation seems more acute than at comparable times in the past. New technologies prompt the formation of new departments or cloud the boundaries between the old; "globalization" moves faculty and administration to re-evaluate the sufficiency of traditional narrow disciplinary course requirements; teamwork and communication seem to require something more. And the problems engineers are expected to confront and help resolve - global warming, sustainable development, energy sufficiency - appear to be of a new kind, reaching beyond the confines of the firm, national boundaries and the customary constraints and specifications of an instrumental nature. The political and the social intrude in ways the engineer is unaccustomed to.

The recognition that improvements need to be made, that the traditional content and teaching methods no longer fit the bill, brings to the fore tensions that have always been part of the growth of programmes in the US. Chief among these has been the tension between "theory" and "practice", between the relative importance given to science, the relative importance given to practice in curricula. Not unrelated is the question concerning who sets criteria for accreditation of programmes and professional status of graduates. And who are the programmes to serve - the student, the needs of industry? How these tensions and questions are addressed depends in part upon tradition and history. The aims and ideas, philosophies and purposes - and perceived avenues for improvement - of today's programmes are rooted in the past.

A brief history

History shows that the genesis of engineering education in the US was the result, not of government policies, but of the efforts of individuals, both scientists and educators well established and of independent means. In 1823, Stephan Van Rensselaer a public figure of some note, together with Amos Eaton, a lawyer, civil engineer versed in the earth sciences, set the groundwork for what was first called "the Rensselaer School" in Troy New York:

"...for the purpose of instructing persons who may choose to apply themselves in the application of science to the common purposes of life...to qualify teachers for instructing the sons and daughters of farmers and mechanics, by lectures or otherwise, in the application of experimental chemistry,

philosophy and natural history to agriculture, domestic economy, the arts and manufactures “ (Wickenden, 1929).

This became, after a decade or so, a professional school of civil engineering (the phrase first appeared in the school’s catalogue of 1828). It was B. Franklin Greene, Eaton’s successor as director who, beginning in 1846, reorganized the school to be a comprehensive polytechnic providing a technical education that went beyond narrow utilitarian concerns. According to Wickenden, “*Greene found his models in the highly developed technical schools of Paris, chiefly the Ecole Centrale des Arts et Manufactures*”. The curriculum of 1850 was of three years duration and included courses in english, foreign languages, and philosophy and over that span of time; another group of the sciences - mathematics, physics and chemistry - were studied in the first two years. The third year was devoted to practical courses including descriptive geometry, mechanics, industrial physics, metallurgy, practical geology, mining, geodesy, machines and construction (structures, bridges, hydraulic works, railways). Wickenden notes as a distinguishing feature “*...the parallel sequences of humanistic studies, mathematics, physical sciences and technical subjects which have marked American engineering curricula to this day.*” An additional preparatory year was deemed necessary and added at the front end to make up for deficiencies in the capabilities of students admitted. This in time became a regular part of a four year programme - the form to this day.

While Greene was not the only person to travel to Paris to find a model for technical education - Col. Sylvanus Thayer, made director of the Military Academy at West Point in 1817, had traveled to Europe to survey military schools and found a model in the Ecole Polytechnique - it was the Rensselaer Polytechnic Institute under Greene’s direction that set the example for other schools, e.g., Union college, Dartmouth, Brown, and the University of Michigan which began instruction in engineering in 1852 under the tutelage of a civil engineering graduate of Rensselaer (1855).

Harvard and Yale started schools of applied science in 1847. But according to Wickenden, Harvard College was “*openly hostile to technical studies*” and this “*...appears to have been a major factor contributing to the establishment of the Massachusetts Institute of Technology on an independent foundation in 1860*”. Yale made better progress, establishing a three-year programme in civil engineering in 1856 and another “on paper” in mechanical engineering that same year. Hostility from the college also made life difficult for faculty holding chairs in mathematics and civil engineering and another in metallurgy but a \$100,000 gift from J.E. Sheffield led to the Scientific School bearing his name and mechanical engineering became a reality.

Up to this point, the establishing of these programmes was the result of hard fought, local and individual effort. But in 1862 the government intervened in a positive way, passing the Morrill Land Grant Act

“without excluding other scientific and classical studies and including military tactic, to teach such branches of learning as are related to agriculture and the mechanic arts, in such manner as the legislatures of the States may respectively prescribe, in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life.”

Each state received a grant of federal land (121 km²) to be used, or the proceeds from its sale to be used, to establish an educational institution having this stated purpose. Within a ten year period, the number of engineering schools went from six to seventy. Other than the requirement that the schools teach military tactic - the justification for today's Reserve Officer Training Programmes (ROTC) - the government kept its distance.

The last quarter of the 19th century saw a move away from shop-work and practice and the emergence of science based instruction - albeit not without resistance from faculty who distrusted theory and who themselves were active in collateral practice. This was fostered in large part by needs in electrical and chemical engineering. Those who taught in these fields were not trained as engineers but in the sciences.

The sciences were to gain further amplification and importance in engineering schools with the arrival of foreign engineers after the first world war but especially in the wake of World War II. Vannevar Bush, President Franklin D. Roosevelt's Director of the US Office of Scientific Research and Development is credited with articulating the fundamental and essential place of science in the development of new products and technologies for the welfare of all mankind. The last half of the 20th century saw funding for research on campus, often in dedicated laboratories, grow by leaps and bounds. One consequence was a significant de-emphasis of the relevance of industrial practice in engineering education.

“... it wasn't until the 1950s,... [that] the federal government decided to fund fundamental research (as opposed to “applied” research) and unleashed an avalanche of money for university programmes, [and] American engineering schools almost universally adopted engineering science as the core of engineering education....

The new emphasis on federally funded research (more than 70 percent of university research was funded by the government) severed the tight linkage between engineering faculty and business corporations. The change was so complete that by the late 1960s practicing engineers were complaining that the pendulum had swung too far toward theoretical concerns, that engineering graduates lacked problem-solving capabilities, and that engineering

faculty and practicing engineers spoke entirely different languages." (Seely, 2005).

Features for comparison

Several characteristics of engineering education in the US emerge from this brief history as worthy for comparison. One concerns the perceived relevance of the humanities and social sciences to the education of the engineer. The structure of the curriculum and the nature of requirements is another. Accreditation of programmes is still another topic for comparison. Finally, we look at the students; at admission requirements and procedures and how the neophyte engineer attains professional status.

The relevance of the humanities and the social sciences

One notable difference in engineering curricula of the US and many countries of the EU (France appears to be an exception) is that, in the US, students are required to accumulate a significant number of credits in the Humanities and Social Sciences. While the history shows a recognition, on the part of those responsible for establishing the first programmes, that to be a considered professional, some measure of the humanities must be an integral part of the curriculum, it was in 1939, with the H.P. Hammond Report, *Aims and Scope of the Engineering Curriculum*, that the Humanities and Social Sciences received explicit and significant status as a "stem" to be offered in parallel with the student's technical track. The report recommended that the humanities and social sciences be given "...a minimum of approximately 20% of the student's educational time. This allotment should be at least the equivalent to one three hour course extending throughout the curriculum, and on the average somewhat more." (Quoted in (ASEE Report, 1956)).

This recommendation became the norm, though the 20% was indeed treated "approximately". The general rule took the form of one HSS course per semester for each of the eight semesters a student was expected to complete for the Bachelor's degree. The importance of "liberal education" as part of the engineer's "professional identity" was re-enforced in the oft cited Grinter *Report on the Evaluation of Engineering Education*, done for the ASEE and published in 1955.

"Looking at the subject of instructional goals even more broadly, one concludes that the engineer should be a well-educated man. He must be not only a competent professional engineer, but also an informed and participating citizen, and a person whose living expresses high cultural values and moral standards. Thus, the competent engineer needs understanding and apprecia-

tion in the humanities and in the social sciences as much as in his own field of engineering. He needs to be able to deal with the economic, human, and social factors of his professional problems. His facility with, and understanding of, ideas in the fields of humanities and social sciences not only provide an essential contribution to his professional engineering work, but also contribute to his success as a citizen and to the enrichment and meaning of his life as an individual.”

In particular, the relevance of courses in the HSS to engineering management was emphasized:

“It is clearly recognized that many engineers progress into managerial and top executive positions in industry and government. For such individuals the foundation should be laid in college for an understanding of human relationships, the principles of economics and government, and other fields upon which the engineering manager can build. The foundation may be built more solidly in humanistic and social courses than in highly applied studies in management.” (Grinter, 1955).

In the 50's, the sequence of courses offered in the humanities and social sciences by different engineering schools varied one school to another but within each programme the student had but limited freedom of choice - compared to today. For example, at MIT, all freshmen engineering students were required to complete a two semester sequence *Foundations of Western Civilization* the first semester of which focused on 5th century Athens, then moved to the Middle Ages. The rise of science and its effects on philosophy and political theory in the 16th and 17th centuries was the focus of the second semester. Similar courses were required at other engineering schools e.g., *History of Western Civilization* at Stanford, *The Background of Western Civilization I, II, III, and IV* at Case Institute of Technology, (an upper-class, four semester sequence). Some required courses at the schools had a decidedly utilitarian purpose, e.g., English composition, Speech, Engineering Economy, but for the most part, the courses - particularly those offered as electives - kept to the “liberal studies” theme.

The Grinter report was quickly followed by another titled *General Education in Engineering* (ASEE Report, 1956) in which the authors explored, through visits to approximately 60 engineering schools and interviews of humanities and social science as well as engineering faculty, how the schools had fared in incorporating study in the humanities and social sciences into the curriculum. Their focus was “*..on the crucial problem of how to develop and maintain an effective programme of humanities and social sciences in the very limited time usually available in an undergraduate engineering curriculum*”.

The committee found that some embraced the notion of including the Humanities and Social Science because they might contribute to the

professional competence of the engineer “...on narrow utilitarian grounds...” through “...the improvement of technical efficiency”. These engineering faculty claimed that in order to write well, to speak effectively, to win friends and influence people, to understand business problems and operations, engineering students “...should take courses in composition, technical writing, speech, applied psychology, and business administration.” Some along this line argued for the study “...of literature and philosophy as subjects which will enable the engineer to manage people more effectively as a result of an improved ability to analyze their motives and points of view.” The committee rejected this rationalization:

“The committee believes that the humanities and social sciences are, in a deeply serious sense, practical and useful. It believes that engineering educators have performed an invaluable service to liberal education by their stubborn insistence that contemporary relevance is the standard by which to judge any humanistic-social programme. What we object to is an essentially frivolous definition of practicality that limits its attention to the development of a few surface skills, while failing to recognize that literature and philosophy and social organization are, like science itself, basic aspects of human activity in which depth of understanding provides the only sound foundation for the student’s future growth. The emphasis upon immediately useful techniques narrows the scope of the humanities and social sciences and seriously diminishes their educational value.”(p.4, ASEE Report, 1956)

The committee went on to denounce (“less defensible”) the “finishing school concept” which holds that the humanities and social sciences provide a “...cultural veneer designed to make the engineer acceptable in polite society.” From this perspective “literature and the arts are primarily conversation pieces, or aids to smoother family and social relations since they give the engineer something to talk about besides transistors, strain computations, and fluid flow.” They sum up “...A statement of objectives which fails to respect the centuries of solid scholarly accomplishment represented by the humanities and social sciences can scarcely provide the requisite intellectual framework for a sound programme of study (in HSS)”. The authors of the *General Education* report presumed that the 20% HSS content would be contained in a sequence or set of courses taken over the students’ four year undergraduate studies but standing apart from their engineering course requirements. This indeed is the structure that endures to this day.

Curriculum structure and requirements

Admission to an engineering school in the US, whether state university or private institution is an opportunity available to all. Of course there are

hurdles to leap; e.g., passing the SATs, a regime of tests taken in the final year of high school at the age of 17 or 18, remain for most colleges and universities a necessity. Letters of recommendation authored by teachers and others in a position to judge the student's accomplishments both inside and outside the classroom are also required. Acceptance depends upon a good measure of subjective judgement as well as the numerical results of the SAT; diversity in the student population is valued. Entrance to an MIT or Stanford or the University of Michigan is highly competitive but if students are truly motivated they can find a place to pursue an engineering degree - and if they excel and succeed at their undergraduate studies, graduate study at a premier institution is a real possibility.

Costs of an engineering education vary significantly when one compares a public and a private institution. For example at MIT, nine months' tuition for 2007–2008 is \$34,750; a Student Activity Fee of \$236 increases the total to \$34,986. Living on campus in a dorm costs approximately \$10,400. (Approximately 90% of undergraduates receive some form of financial aid). For comparison, at the University of Massachusetts at Amherst, tuition and fees for a resident of the Commonwealth of Massachusetts is approximately \$5000; for students from outside the state, it is approximately double that amount.

The undergraduate engineering education curriculum in the US as a whole has hardly changed since the 50's as measured by the fraction of time devoted to the different kinds of courses constitutive of an undergraduate programme. For example, at MIT, student credit hours in the humanities and social sciences amount to approximately 20% of the total required to obtain the Bachelor of Science degree in a designated field such as mechanical engineering. Required courses in mathematics (Calculus, Differential Equations) and science (Chemistry, Physics, and now Biology) account for another 20 - 25%. Engineering science courses, including laboratories, consumes 25% of the student's life on campus; engineering design, roughly 10%, advanced courses in whatever subfield the student may elect, roughly 10%, leaving the balance, approximately 10%, as free electives.

If one takes a bird's eye view, this structure appears not all that different from what it was in the 50's. One has to look up close at the content and methods within a category to see the extent of significant change. Design is no longer limited to machine design and mechanical drawing, for example. The humanities requirement is no longer so rigid; the *Western Civilization* courses are gone the way of all things limited to white, western and male. But studies in the humanities remains a requirement, substantial in scope and depth.

The fore-mentioned required courses in the calculus and in the sciences also distinguish engineering programmes in the US from those in the EU. This reflects the more advanced standing and capabilities of entering students in the EU. In France, for example, two years in a 'classe

préparatoire' where mathematics and physics are studied intensely is prerequisite to taking a competitive exam in seeking admission to one of the 'grandes ecoles' in engineering.

Accreditation - ABET

The official history of the Accreditation Board for Engineering and Technology (ABET), since 2005 renamed ABET, Inc., dates its birth to 1932, the year the Engineers' Council for Professional Development (ECPD) was established. This organization of seven engineering societies - The American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the Society for the Promotion of Engineering Education, the American Institute of Chemical Engineers, and the National Council of State Boards of Engineering Examiners - focused on four areas: guidance, training, education and professional recognition. (ABET. History, 2008).

According to Edwin Layton, licensing was also very much on the minds of the engineering societies. In the depression years there was an oversupply of engineers and ways were sought to limit membership in the "profession". The ECPD became a forum for debate, seeking "...some means of drawing a sharp line between professional engineers and other technical workers". But little was done in this regard; the conservatism of the different founding societies and their different definitions of membership grades prevented agreement to even a modest system for "certification". (Layton, 1971).

One less contentious way to maintain professional status was to ensure that engineering degree programmes were of high quality; the year after its founding, ECPD began evaluating such programmes. By 1940, "...through the inspection programme of its committee on engineering schools..." ECPD had accredited 461 engineering curricula at 129 colleges and universities in the US. Another 104 curricula received provisional accreditation. (Engineer's Council, 1941)

It wasn't until 1980 that ECPD was renamed the Accreditation Board for Engineering and Technology (ABET) "...to more accurately describe its emphasis on accreditation." (Lattuca et al. 2008). And in 2005, the label changed to simply "ABET, Inc." - a step that "...allows the organization to continue its activities under the name that represents leadership and quality in accreditation for the public while reflecting its broadening into additional areas of technical education." according to the official history. Currently, the number of accredited programmes has grown to 2,700 at 550 colleges and universities.

A significant change in ABET's programme evaluation criteria was made in 1997. After several years of discussion and debate the criteria moved from "bean counting", i.e., ensuring that a degree programme required specific

science and engineering courses relevant to the particular discipline, to an outcomes-based assessment with the added demand for continuous programme improvement. The new criteria, Engineering Criteria 2000 (EC2000) were meant to foster innovation as well as assure a programme's worth.

“The revolution of EC2000 was its focus on what is learned rather than what is taught. At its core was the call for a continuous improvement process informed by the specific mission and goals of individual institutions and programmes. Lacking the inflexibility of earlier accreditation criteria, EC2000 meant that ABET could enable programme innovation rather than stifling it, as well as encourage new assessment processes and subsequent programme improvement.” (ABET. History, 2008)

ABET lists eight “General Criteria for Baccalaureate Level Programmes”: Students; Programme Educational Objectives; Programme Outcomes and Assessment; Professional Component; Faculty; Facilities; Institutional Support and Financial Resources; and Programme Criteria. The “programme educational objectives are broad statements that describe the career and professional accomplishments that the programme is preparing graduates to achieve.” Programme outcomes “...describe what students are expected to know and be able to do by the time of graduation”. These are specified as follows:

- (a) an ability to apply knowledge of mathematics, science, and engineering*
- (b) an ability to design and conduct experiments, as well as to analyze and interpret data*
- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*
- (d) an ability to function on multi-disciplinary teams*
- (e) an ability to identify, formulate, and solve engineering problems*
- (f) an understanding of professional and ethical responsibility*
- (g) an ability to communicate effectively*
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context*

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

In addition, an engineering programme must demonstrate that its students attain any additional outcomes articulated by the programme to foster achievement of its education objectives.

The ‘Professional Component’ criteria lists subject areas that must be included in a programme in general terms - college-level mathematics, basic sciences, engineering design and a ‘general education component’ that complements the engineering courses. The criteria include the number of years that must be devoted to each category but do not spell out specific courses.

This shift from requiring specific courses to managing a process has not come without its costs; we see the appointment of evaluation leaders and specialists to collect data and lead faculty through the assessment process at each college and university. Faculty complain about the number of forms to be filled out, the time spent to collect data, and hours in meetings to try to live up to the “spirit of EC2000”. Is it worth it?

“Today, the spirit of EC2000 can be found in the evaluation criteria of all ABET disciplines, and studies like Penn State’s Engineering Change prove those criteria are having an impact on accredited programmes.” (ABET. History 2008)

The positive impact of the change, both on student learning outcomes and on organizational and educational policies and practices, appears to be a greater emphasis on professional skills and active learning and high levels of faculty support for continuous improvement. Yet while, “...half to two-thirds of the faculty report that they have increased their use of active learning methods, such as group work, design projects, case studies, and application exercises, in a course they teach regularly”,(Engineering Change, 2006) there was little evidence that any major renovation of these courses regularly taught, any major programmatic renovation, had been stimulated by EC2000. There is evidence nonetheless that the changes are positive in respect of creating a new paradigm for delivery of engineering education and facilitating the empowerment of graduates by providing them with the academic and societal skills necessary to contribute as professionals in today’s ever changing and challenging world. We are asking questions and

getting to know each another's ways, not only at national level but between Europe and the US and across the greater global divides, an essential requirement to tackling the major problems, not least energy, facing us today.

Summary

This brief comparison points to several ways in which programmes in engineering education differ across the Atlantic. (It suggests, too, that differences among programmes in the EU are as great as between those of the US and the EU - as those attempting to restructure in accord with the Bologna agreement are discovering). Generally speaking, programmes within the EU appear more regimented in the requirements for admission relative to the US, the hurdles one must leap, more standardized, 'objective' and preparatory courses limited in the main to mathematics and science. This reflects the more rigorous, as well as regimented, preparation prevailing in Europe where the education standard for entry to the profession is largely through completing a five year diploma/degree programme at Master degree level.

In the US, students have a wide variety of engineering schools to which they may apply for admission - public or private, small college or large university, near home or far afield. Within a member state of the EU, programmes have more of a standard character, but variation from country to country is as wide as in the US, perhaps more so and this in terms of programme content as well as size, etc. A project-based learning programme at Aalborg differs significantly from a classical engineer degree programme at Cambridge. A product design programme at Delft contrasts with science based curriculum at the Ecole Polytechnique. The Bologna accord is intended to create a European area of higher education within which Bachelor Degree graduates may transfer to Master degree programmes in any university in any European country thereby significantly increasing student mobility throughout the area.

The relationship of the institution, whether college or university, to the state has a different nature: While schools in the US rely upon federal funding for research (and the guarantee of student loans) relationships with agencies, including laboratories, of the government do not have the same intensity as they do in the EU. In the EU, state subsidy of the student's educational expenses is often direct and traditional. In the US, even public (state) schools require their students to cover a significant portion of the costs of their education.

In marking all of these differences, and we have not done much more, differing historical contexts reveal the roots and reasons for why programmes in engineering education are as they are. Tradition will also continue to guide and constrain their form in the future.

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