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EFCE Bologna Recommendations

Recommendations for Chemical Engineering Education in a Bologna Three Cycle Degree System

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Foreword by the EFCE Scientific Vice President

Europe's educational system is going through what may be its greatest change since the invention of the university in Italy in the eleventh century AD. This is particularly true for all the new degree programs that are being created within what is colloquially known as the "Bologna Process". The Bologna declaration in 1999 was the start of the introduction of a three cycle degree system in Higher Education in Europe. Nowadays many European universities have adopted this degree structure.

The document which follows is the culmination of many years' work to assist institutions delivering degrees in chemical engineering and their accrediting bodies. The Working Party on Education (WPE) of the European Federation of Chemical Engineering (EFCE) firstly carried out research to determine the contents of higher education in chemical engineering, and related disciplines such as applied chemistry and process engineering, throughout Europe. Further work was required to determine the minimum set of subjects required to define a course as chemical engineering and the level of achievement which might reasonably be expected at different levels. For example programmes comprising hardly any mention of subjects so fundamental for the profession as, for example, thermodynamics, fluid mechanics transport phenomena, separation techniques or reaction engineering, should not be recognised as chemical engineering, irrespective of the name of the course or the standing of the institution.

The outcome of this was a set of recommendations for first and second cycle in chemical engineering education aligned with the Bologna Process, published in 2005[1]. This was widely welcomed and many bodies in different countries used the EFCE recommendations as a basis for their "new" chemical engineering curricula. Since this time, the Working Party has taken note of (and some members have been involved in) further developments in harmonization of European higher education. I should particularly note the Leuven Communiqué of April 2009, which included the statements: "We reassert the importance of the teaching mission of higher education institutions and the necessity for ongoing curricular reform geared toward the development of learning outcomes. ... Academics, in close cooperation with student and employer representa-

[1] EFCE Bologna Recommendations 2005: www.efce.info/Bologna_Recommendation.html

tives, will continue to develop learning outcomes and international reference points for a growing number of subject areas."[2] *On national and international level many accreditation bodies also defined quality frameworks and learning outcomes for programmes in the field of engineering, including chemical engineering.*

Now the EFCE has revised the recommendations in order to strengthen the outcome orientation, and has added a description of outcomes for the third cycle. Being aware of the various cultures in the European countries and wide variety of fields in which a chemical engineer may complete a doctorate, the third cycle is focussed on more general learning outcomes. However, these are considered in addition to the more specific first and second cycle proposals.

At this point a few words of comment seem appropriate:

The Federation has no intention to enforce any ready made teaching programmes on the institutions of higher learning, or to hinder the development of new concepts of study. The Working Party on Education is very much aware of and involved in new methods of education, and appreciates the new topic which may be legitimately brought into a chemical engineering course. Tables of course content and credits are given as exemplars, not requirements, and in any case only amount to two-thirds of the study time. However, we do not believe there is much which could be omitted from this core without bringing into question the validity of the course as a chemical engineering qualification. We also recognise that people may take other routes, e.g. by conversion from cognate disciplines, but should expect to achieve most of these core outcomes in their overall education.

It is hoped that these revised EFCE recommendations will help institutions of higher education to educate young chemical Engineers in all three cycles who are capable of solving those problems we will face in tomorrow's Europe.

Dr. Hermann J. Feise
(EFCE Scientific Vice President)

[2] Communiqué of the Conference of European Ministers Responsible for Higher Education, Leuven and Louvain-la-Neuve, 28-29 April 2009: www.ond.vlaanderen.be/hogeronderwijs/bologna/conference/documents/Leuven_Louvain-la-Neuve_Communiqué_April_2009.pdf

Introduction

According to the 2001 and 2003 communiqués of the Bologna Follow-up Conferences of the Ministers responsible for Higher Education, “first and second cycle degrees should have different orientations and various profiles in order to accommodate a diversity of individual, academic and labour market needs”. Therefore in a number of countries in Europe we can distinguish two types of higher education in chemical engineering: “more research-oriented” first cycle (“bachelor”) programmes and more “application-oriented” first cycle programmes. Both types of programmes cover a study of three or four academic years each of 60 credits (total 180-240 credits). The length of the programmes may depend on the length of pre-university education (age of students 17 or 18 years old). After completion of the undergraduate, first cycle (“bachelor”) curriculum, students can continue their study with a second cycle (“master”) programme in chemical engineering of 90-120 credits (1 ½ - 2 academic years).

The recommendations for the first and the second cycle adopt the EUR-ACE® framework standards for accreditation of engineering programmes[3], being grouped in the following Programme Outcomes:

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

The recommendations accommodate the outcomes of both “more research-oriented” and “more application-oriented” chemical engineering programmes, the differences being that the latter tend to show less scientific depth but more practical competencies.

The document further covers some recommendations for achieving these programme outcomes containing:

- Core curriculum
- Teaching and learning
- Industrial experience
- Review of the educational process
- Student assessment

The programme outcomes are formulated in a general way, to emphasise what should be common to chemical engineering education. The core curriculum proposed here with additional appropriate topics in science, in chemical and other engineering, and in non-technical areas will give a variety of concrete contents to the general outcomes. Thus, different chemical engineers will be able to handle the demands of different industries and tasks: e.g. oil refining, bulk and fine chemicals, paper, polymers, food, cosmetics, pharmaceuticals, environmental issues. Particularly second level graduates will be able to perform research tasks and go on to doctoral studies.

[3] European Accreditation of Engineering Programmes;
www.enaee.eu/pdf/EUR-ACE_Framework_Standards_20110209.pdf

A large percentage of chemical engineers are now engaged in making various specialty products (formulated products), and relatively fewer in making traditional commodity chemicals. While all chemical engineers still need many of the traditional chemical engineering skills, the EFCE feels there is now a need to include some knowledge of "product engineering" in the common core in order to reflect the increasing importance of modern materials science.

Further, these recommendations give the higher education institutions the opportunity to introduce their own "flavour" and/or innovative concepts in their programmes. For this reason core curricula are proposed which cover only two thirds of a first cycle ("bachelor") programme and the framework of a second cycle ("master's") degree.

Programme outcomes

In line with recommendations/requirements from other bodies (including accreditation bodies), EFCE has formulated its recommendations first and foremost as programme outcomes, i.e. what the students should know or be able to do immediately after graduation.

First Cycle ("bachelor") Chemical Engineering programme outcomes

After graduation, a first cycle degree chemical engineer should meet the following criteria:

- Knowledge and Understanding
    - The graduates have acquired basic knowledge of mathematics, physics, chemistry and biology which enables them to understand the phenomena which occur in the field of chemical engineering.
    - They have acquired the fundamental principles of chemical engineering for the modelling and simulation of chemical reactions and bio molecular processes, of energy, mass and momentum transport processes, and of separation processes.
    - They are familiar with the basic principles of measurement techniques and control.
- Engineering Analysis

  The graduates have the ability:
    - to identify problems in their subject and to abstract, formulate and solve them holistically using fundamental principles;
    - to consider, analyse and evaluate products, processes and methods of their subject on a systems engineering base;
    - to select and apply suitable methods of analysis, modelling, simulation and optimisation.
- Engineering Design

  The graduates have:
    - the ability to develop a basic design for products and processes according to specified requirements;
    - a basic understanding of design methods and the ability to apply them
- Investigations

  The graduates are able:
    - to tackle a real chemical engineering problem by a scientific approach:
    - to use library and web resources for the acquisition of information regarding equipment characteristics and design methods, physical properties, kinetic and thermodynamic data:
    - to demonstrate effective communication skills, both in writing and presentation, and to work effectively in teams:

- o to make an appropriate safety assessment before starting experimental work:
- o to plan and carry out experiments and interpret the results with guidance of a senior scientist (chemical engineer).

- Engineering Practice

  The graduates have:

  - o the ability to combine theory and practice in order to analyse and solve problems of engineering science using methods based on fundamental principles;
  - o understanding of applicable techniques and methods and their limits;
  - o the ability to apply their knowledge of different areas taking safety measures and ecological and economic demands into account responsibly, and also to extend their knowledge on their own responsibility;
  - o the ability to organise and carry out projects;
  - o the ability to work with specialists from other disciplines;
  - o the ability to present the results of their work in both written and oral form in an articulate way;
  - o an awareness of the non-technical implications of engineering practices.

- Transferable Skills

  The graduates are able to:

  - o communicate effectively, including in English, with specialists and non-specialists, using modern presentation tools as appropriate;
  - o work individually and as team members in international and/or multidisciplinary teams;
  - o understand the impact of engineering solutions in an environmental and societal context;
  - o understand professional and ethical responsibility;
  - o learn on their own, and recognise the need for life-long learning.

Second Cycle ("master") Chemical Engineering programme outcomes

After graduation, a second cycle ("master's") degree chemical engineer should fulfil the following qualifications:

- Knowledge and Understanding
  - o The graduates have acquired extensive and profound knowledge of mathematics, chemical engineering and other sciences which enable them to carry out scientific work and to act responsibly in their professions and in society. They are aware of new developments in their field.

- Engineering Analysis

  The graduates are able to:

  - o analyse and solve problems scientifically, even if the definitions are incomplete or are formulated in an unusual way and show competing specifications;
  - o abstract and formulate complex problems from a new or a developing field;
  - o apply innovative methods in solving problems based on fundamental principles

- Engineering Design

  The graduates are able to:

  - o develop concepts and solutions to problems based on fundamental principles but also to problems which are posed in an unusual way – if necessary involving other fields;
  - o develop new products, equipment, processes or methods;

- use their powers of judgment as engineers in order to work with complex and possibly incomplete information, to recognise discrepancies and to deal with them.

- Investigations
  The graduates are able to:
  - tackle a real chemical engineering problem by a scientific approach:
  - recognise the need for information, to find and provide information:
  - plan and carry out theoretical and experimental research independently:
  - evaluate data critically and to draw conclusions from it:
  - examine and evaluate the application of new and emerging technologies.

- Engineering Practice
  In addition to the qualification acquired during their first cycle degree course, the graduates are able to:
  - classify knowledge from various fields methodically and draw systematic conclusions from it and also to deal with complexity;
  - familiarise themselves with new tasks systematically and without taking too long;
  - think systematically about the non-technical effects of an engineer's job and to include these aspects responsibly in what they do;
  - find solutions which require very considerable competence as far as methods are concerned.

- Transferable Skills
  In addition to the qualification acquired during their first cycle degree course, the graduates are able to:
  - function effectively as a member of a team that may be composed of different disciplines and levels;
  - work and communicate effectively in national and international contexts.

The EFCE expects that the final outcomes of second cycle ("master's") degree programme to be (at least) equivalent to those of traditional long-cycle (4½ – 5 years) programmes.

Third Cycle ("doctorate") Chemical Engineering outcomes

In addition to the qualification acquired during the first and second cycle, a graduate of the third cycle will:

- have demonstrated a systematic understanding of a field of study and mastery of the skills and methods of research associated with that field;
- have demonstrated the ability to conceive, design, implement and adapt a substantial process of research with engineering integrity;
- have made a contribution through original research that extends the frontier of technology and knowledge by developing a substantial body of work, some of which merits national or international refereed publication and/or could result in patents;
- be capable of critical analysis, evaluation and synthesis of new and complex ideas and be able to justify choices taking into consideration technological, societal, temporal and economic constraints;
- be able to develop project plans and required resources in international context.
- be able to communicate with their peers, the larger international scholarly community and with society in general about their ideas or expertise;

- be able to promote, within academic and professional contexts, technological, social or cultural advancement in a knowledge based society.

Achieving the learning outcomes of the first cycle and second cycle

To ensure the proper common content and proper levels of the different first and second cycle degrees, EFCE recommends minimum requirements for certain subjects and topics (e.g. mathematics and reaction engineering) that form the core curriculum for the each cycle.

Although the first cycle ("bachelor") core curriculum is more detailed than the second cycle ("master") programme, there is still much of the total study left (one academic year) to give the institutions the opportunity to implement their own specialism and/or new development in the field of chemical engineering.

For the second cycle the recommendations are very general, making it easy to give a broad range of different orientations within and between institutions while meeting the general outcomes.

Note that the curriculum recommendation lists topics. EFCE makes no recommendation on the number of courses that should be given, or on how topics should be grouped in courses. Furthermore, in practice many of the listed topics will be part of larger courses containing more than just the core.

As the common European credit unit is the ECTU (European Credit Transfer Unit) of which there are 60 per year, all recommendations here are given using ECTU. The EFCE has chosen a 3 + 2 years two cycle scheme as an example. For other schemes the figures have to be adapted accordingly.

First Cycle ("bachelor") Chemical Engineering programme

Core curriculum Chemical Engineering (first cycle)	*Credits (minimum requirements)*
Fundamentals of science and natural sciences mathematics, computer science, physics, chemistry, biology	45
Chemical Engineering fundamentals material and energy balances, thermodynamics, fluid dynamics, heat and mass transfer, separations, chemical reaction engineering, bio molecular and biological engineering	35
Chemical Engineering applications e.g. basic product engineering, safety, health and environment, design and process analytical techniques	15
Non-technical subjects e.g. economics and management	10
First Cycle ("Bachelor's") thesis project	15
Total of the recommended core curriculum	120
Chemical engineering sciences or natural sciences according to the main emphasis of the degree course of the university	60
Total of a first cycle chemical engineering degree programme (minimum requirement)	**180**

Typically, a first cycle ("bachelor's") degree course will contain 20-30 % science courses, 40-50 % engineering courses, and up to 10 % non-technical topics. The core recommended here gives a science content of 25 %, an engineering content of 36 %, and a non-technical content of 6 % of the total study (180 credits), leaving one third to deeper coverage of some of these topics and to other topics.

Second Cycle ("master") Chemical Engineering programme

Although no topics are specified here, it is clear from the recommended learning outcomes that central chemical engineering topics such as transport phenomena, chemical reaction engineering, dynamic modelling as well as general topics such as statistics/optimization/parameter estimation must be included to the extent they have not already been covered in the bachelor study.

Core curriculum Chemical Engineering (second cycle)	*Credits (minimum requirements)*
Mathematics and science Extension of mathematical and scientific subjects	15
Chemical Engineering topics e.g. advanced courses in multphase reactor engineering, catalysis, transport phenomena	40
Second Cycle ("Master's") thesis project	20
Total of the recommended core curriculum	75
Chemical engineering sciences or natural sciences according to the main emphasis of the degree course of the university	15-35
Total of a second cycle chemical engineering degree programme	**90-120**

The core curriculum makes up 63 % of the total study (of 120 credits), leaving 37% of the second cycle ("master") study for additional specialization and broadening.

Teaching and learning

Irrespective of the degree structure, the teaching and learning methods must be appropriate for the topic in question, and be chosen so that the learning outcomes can be achieved. The teaching and learning methods should also help develop students' skill to work both independently and in teams. Thus, to learn to function in teams, group work is necessary. To be able to communicate, communication tasks must be given and solved. To learn to learn and to take responsibility for their own learning, students must be given appropriate self-study and problem solving tasks during their study. To understand ethical, societal, environmental and professional issues, suitable examples for illustration or discussion must be included. The study should be organised to ensure that students work during all of the semester, and are able to make the relevant connections between the different subjects.

All courses should as far as possible give examples from several areas, to show the broad applicability of chemical engineering methods.

Industrial experience

Industry has an important role to play in the education of chemical engineers. Industrial experience serves to illustrate the applications and limitations of theory, helps to set the courses in a wider context and motivates for the remaining study. In addition, it provides social skills for later leadership roles. Industrial experience for all can only be obtained if industry accepts the responsibility of providing sufficient placements.

International dimension

Chemical engineering graduates are typically employed in companies and organisations that are operating globally. Therefore, each educational institution is recommended to employ an active strategy for internationalisation. This means the process of integrating an international, intercultural, or global dimension into the purpose, functions or delivery of higher education. In practice, internationalisation may include student and staff mobility, internationalisation at home as well as international benchmarking and accreditation.

Review of the educational process

Each educational institution should have an ongoing review of the educational process, to ensure that the parts are up to date and properly coordinated, and that each and every part contributes towards the aims of the course, and in general to improve the educational outcomes.

Student assessment

EFCE would like to emphasise the need for appropriate feed-back to maximise the learning effect of the assessments.