

CHEMICAL ENGINEERING EDUCATION IN EUROPE Trends and Challenges[†]

M. MOLZAHN*

EFCE Working Party on Education, Weisenheim am Berg, Germany

At least three major issues influence the education of chemical and process engineers in Europe at the beginning of the new century. First a lack of students entering chemical engineering programmes in several European countries, second the process towards a harmonized higher education area in Europe (Bologna Process), and finally a distinct uncertainty as to what chemical engineering as well as education in chemical engineering should be in the future. All three of these issues require full attention by the chemical engineering community. This paper will discuss them against the background of actual experiences gathered by the EFCE Working Party on Education.

Keywords: chemical engineering; process engineering; education; Bologna Process; outcomes.

INTRODUCTION

Some years ago Gillett presented a paper, in which he summarized the work of the EFCE Working Party on Education and discussed the challenges for the education of chemical engineers mainly in Europe, which are caused by the rapid rate of change in technology and society worldwide. He came to the conclusion that curriculum development, personal development and life-long learning will become the three most important factors for educating chemical engineers for a successful future (Gillett, 2001). A little later Molzahn and Wittstock discussed the challenges for university education in chemical engineering at the beginning of the 21st century. Their focus was mainly the situation in Germany. They stressed the need for more competition between individual universities as well as the necessity to reform and update the content and structure of study programmes offered. This included the courage not to try and cover everything. They emphasized the role of universities in shaping the future of higher education in Germany as one of the major challenges (Molzahn and Wittstock, 2002).

Despite the fact that both of these papers were published after the turn of the millennium they did not take note of the Bologna Process as a European challenge. Molzahn and Wittstock at least have dealt with some aspects of the introduction of Bachelor and Master Degree Programmes only against the background in Germany.

The 4th European Congress of Chemical Engineering gave the opportunity to ask again what are now, only a few years later, the major challenges for chemical engineering education in Europe. From the point of view of the members of the Working Party on Education of the European Federation of Chemical Engineering (EFCE) they are: first, a lack of students entering chemical engineering programmes in several European countries; second, the process towards a harmonized higher education area in Europe (Bologna Process); and finally, a distinct uncertainty as to what chemical engineering as well as education in chemical engineering should be in the future.

A LACK OF STUDENTS

In several European countries universities are suffering increasingly from a decline of student applications for chemical engineering as well as for some other engineering and sciences programmes of study. In 2003 the members of the EFCE Working Party on Education have given short statements on the actual situation in chemical engineering and related fields in their countries:

- Czech Rep.: huge decrease since 1997
- France: no decrease in short (2a, DUT) and long programmes (5a, ID), large decrease in medium programmes (3a, DEUG)
- Germany: constant on a low level, increasing in bioprocess engineering
- Norway: below actual capacity
- Portugal: applications exceed capacity
- Spain: applications exceed capacity
- Switzerland: stable in chemical engineering, increasing in process and bio-process engineering
- UK: departments are desperate to fill vacancies

*Correspondence to: Dr M. Molzahn, Independent Consultant, Auf'm kies 12, D-67273 Weisenheim am Berg, Germany.
 E-mail: martin.molzahn@t-online.de

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It is obvious that apart from the countries in south-western Europe the others are observing either a decrease of students entering into chemical engineering programmes, or are living with a number of students far below the actual capacity of their universities, and most probably below the future needs of their industries too.

Figure 1 may illustrate the situation in Germany: Starting in 1985 it shows the development of the number of first year students (1985 = 100%) in all disciplines (1985: ~205.000), in all engineering disciplines (1985: ~49.000), and in chemical and process engineering (1985: ~3.000). Since 2000 the total number of freshmen after a minimum between 1994 and 1997 has clearly exceeded the maximum value of 153% in 1990 and is now approaching the 200% line. The number of young students in all engineering disciplines together is now approaching the maximum value of 133% in 1990. In contrast to this the number of first semester students in classical Chemical and Process Engineering has heavily decreased in the early nineties to a minimum value of about 35–40% and has remained at such a low level for many years.

If this situation continues much longer, it will lead to further severe consequences for the universities as well as for the industry. It is not only the case that universities are suffering a lack of young researchers and academics. Several higher education institutions have already shut down the Chemical Engineering departments, and used the resources in other departments or institutions.

Various reasons for the declining interest in studying for an engineering profession have been discussed elsewhere: A number of studies suggest that socio-political factors such as the level of technology acceptance are not solely responsible. However, it is nowadays less common for parents or other persons to whom they relate, to advise young people to study a natural science or a technical subject; other disciplines such as business, accountancy, law, psychology, and medicine appear to be more attractive than engineering studies, which are regarded as more difficult and less lucrative (Zwick and Renn, 2000). Of great influence seems to be the actual situation in the job market for engineers, which includes early retirements, layoffs, and cautious recruiting practices by the employers. Especially in the field of Chemical Engineering we can observe additionally a lack of information about the contents

of the discipline, and about the career prospects as a chemical or process engineer.

In order to overcome some of the abovementioned hindrances several initiatives have been developed at various places to attract young people to Chemical Engineering and related programmes. As one example, the chemical engineering faculty of the Norwegian University of Science and Technology (NTNU) at Trondheim has started a formal cooperation with a number of larger process companies in Norway, which then finance recruiting activities and also provide summer jobs and projects. One of the recruiting activities is to send out some of the students to their former high schools where they can report about the studies and the possibilities afterwards. They get a little training before they are sent out. They contact their previous teachers to make sure they get to talk to one class at a time. Part of this recruiting work is geared to making the high school students choose enough mathematics and sciences in time to keep their options open (Løvland, 2003).

A second example may be Germany: there exist many initiatives to recruit young people for Engineering, Chemical Engineering and Sciences studies and professions running for several years. Table 1 gives an overview. It shows that all initiatives are focussing on providing better information to young people. The methods they are using are different: some are based on delivering information by speakers (e.g., young engineers) like in Norway; others are additionally based on a learning-by-doing concept with small projects in cooperation between schools and industry. The initiative JUTEC finally intends to establish the topic technology in all primary and secondary school curricula; it seems to be the initiative with the greatest impact and the best long-term effect, if it will be successful. It could provide a good basis for all the specific information delivered by the other initiatives (Daun, 2000).

Some years ago in the UK the Institution of Chemical Engineers has started a web based initiative called 'Why not Chem Eng?', which provides a dynamic online resource for coming students, parents and teachers in order to inform in an attractive way about the profession. Part of that approach have been special all expenses paid courses for secondary school teachers at several universities which 'dramatically will bring Chemical Engineering to life' (IChemE, 2000).

Another way frequently used to increase the number of applicants to chemical engineering departments is to offer additional programmes with the suffix 'bio' like 'Bio Process Engineering' or 'Bio Engineering'. These programmes seem to be very attractive to young people. Figure 1 shows, that since 2001 the total number of admissions to Bio- and Chemical-Process Engineering programmes is steeply increasing, nearly approaching the 100% line. Some departments are already reaching their capacity limit. These programmes are also attracting young people, who never would have applied for classical engineering programmes. While in the first years many of them have been very astonished to be confronted so soon with a lot of hard stuff like mathematics, chemistry, and physics as well as with engineering basics, and then left the courses within the first semesters, the later students have been better informed about the expectations and can handle what is required by

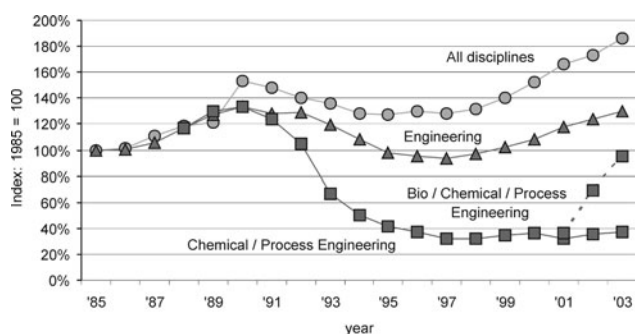


Figure 1. First year students at higher education institutions in Germany since 1985 (Sources: German Federal Statistical Office, Hochschulinformationssystem (HIS), personal inquiries (Universities of Dortmund, Erlangen, and Karlsruhe).

Table 1. Initiatives in Germany to recruit young people for engineering and chemical engineering studies and professions (Daun, 2000).

| Initiative | Sponsor(s) | Extension | Target group | Objective |
|------------|--|-------------------------------|--|---|
| JUTEC | VDI | Countrywide | Teachers and students at primary and secondary schools | To establish technology in primary and secondary school curricula |
| Think-Ing | Employers associations (<i>Gesammetall</i> , VDA, VDMA, VDE, ZVEI), VDI | Countrywide | Teachers and students at upper secondary schools | To inform about engineering studies |
| BOGY | Ministry of education and state employment agency Baden-Württemberg | <i>Land</i> Baden-Württemberg | Students at secondary schools | To inform about studies and professions in different fields |
| Theoprax | <i>Fraunhofer-Gesellschaft</i> | In 6 <i>Länder</i> | Students at lower and upper secondary schools | To combine theory and practical work by projects and teamwork in cooperation between schools and industry |
| DECHEMAX | DECHEMA | Countrywide | Students at lower and upper secondary schools | To fill them with enthusiasm for chemistry, technology and biology |
| KJVI | VDI-GVC | Countrywide | Students at secondary schools | To inform about chemical and process engineering |

them. So this change of the scope of Chemical Engineering programmes seems to be a convenient way to cope with the changing demand of customers, provided they will get a profound education also in classical Chemical Engineering, so that they will be able to work in a wide field of industries.

THE BOLOGNA PROCESS

Objectives and Elements

The second major issue influencing the education of chemical engineers within the next few years is the so-called Bologna Process, which aims 'to establish the European area of higher education within the first decade of the third millennium' (Bologna, 1999). It has been started officially by the ministers in charge of higher education of 30 European countries when signing their joint declaration in Bologna in June 1999. The main objectives and elements of this process are:

- Adoption of a system of easily readable and comparable degrees, also through the implementation of the Diploma Supplement.
- Adoption of a system essentially based on two main cycles, undergraduate and graduate. Access to the second 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 degrees as in many European countries.
- Establishment of a system of credits—such as in the European Credit Transfer System (ECTS, 1997)—as a proper means of promoting the most widespread student mobility. Credits could also be acquired in non-higher education contexts, including lifelong learning, provided they are recognized by the receiving universities concerned.
- Promotion of mobility by overcoming obstacles to the effective exercise of free movement with particular attention to students, teachers, researchers, and administrative staff.
- Promotion of European co-operation in quality assurance with a view to developing comparable criteria and methodologies.

- Promotion of the necessary European dimensions in higher education, particularly with regard to curricular development, inter-institutional co-operation, mobility schemes and integrated programmes of study, training and research.

The reasons for starting this process can be summarized from the outcomes of the Sorbonne conference in 1998, where the ministers in charge of higher education from France, Italy, UK and Germany met to initiate the harmonization—but not the levelling down—of the European higher education system (Sorbonne, 1998):

- The national systems of higher education in Europe have been proven to put more and more hindrances that prevent the mobility of students and employees: Degrees are most often awarded and accredited solely on a national basis, but have to be recognized by the international labour market.
- The attraction of European higher education to students and academics from other parts of the world has decreased continuously because of problems with its external and internal readability.
- European students are asking increasingly for transnational programmes of study.

Milestones

Two years after signing the Bologna Declaration a first follow-up conference took place in Prague in May 2001. There three more countries joined the Bologna Process; so today all actual members of the European Union as well as all those countries are involved which will become an EU member next year or which intend to do so in a longer view. As an outcome of this conference two more elements of the process have been defined, and two more procedural issues have been stressed (Prague, 2001):

- Promotion of lifelong learning as an essential element of a knowledge-based society.
- Enhancing the attractiveness and competitiveness of the European higher education area to other parts of the world.
- Involvement of students and higher education institutions.
- Continued follow-up to review progress and set directions and priorities for the next stages of the process.

Additionally the ministers made an important statement with respect to diversity in European higher education when noting that 'in many countries Bachelor's and Master's degrees, or comparable two cycle degrees, can be obtained at universities as well as at other higher education institutions. Programmes leading to a degree may, and indeed should, have different orientations and various profiles in order to accommodate a diversity of individual, academic and labour market needs as concluded at the Helsinki seminar on bachelor level degrees' (Helsinki, 2001).

The second Bologna follow-up conference took place at Berlin in September 2003. There seven more countries have signed the Bologna Declaration. As one additional element of the Bologna Process the ministers have defined Doctoral Studies as a third cycle of study, which can be accessed after completing the second cycle, as well as an element linking the European Higher Education area with the European Research area. Also the relevancy of a first level degree to the European labour market has been discussed again. Finally the ministers have agreed to speed up the whole process (Berlin, 2003).

To prepare for the Berlin conference all countries involved have been asked to deliver official reports on the actual status of their implementation. From these reports one can see that in all countries involved, a lot of activities have been started: new laws have been delivered or are in preparation, accreditation bodies have been established, international networking has been intensified, and many new programmes of study according to the Bologna concept have been introduced in many countries (Reports, 2003). One can say that some progress has already been achieved. But, several questions still remain unsolved; some of them will be discussed now.

Engineering Education in Europe

So far we have looked at the overall objectives of the Bologna Process, which have to apply to all fields of study. When now focusing on higher engineering education in Europe it will become obvious that so far, two principal concepts exist: one widespread in Continental Europe and the other primarily in Ireland and UK.

With a little simplification, it can be said that engineering education in Continental Europe follows two basic models, often coexisting in parallel within each country (TNE4, 2002):

- The first model, referred to often as 'long cycle engineering education' or 'integrated second level degree education', is characterized, firstly, by a strong theoretical base and, secondly, by a strong orientation to research. Its nominal duration is intended to be round about five years.
- The second model is referred to as 'short cycle engineering education'. The programmes are of three to four years duration, they are more oriented to application, and there is often a stronger emphasis on formal teaching. These courses are usually provided by separate institutions, but in some countries they are provided by the same institutions, that provide the 'long cycle' courses too.

This situation has been addressed by the Prague conference as mentioned above.

In Ireland and the UK we find courses which already have the formal structure of the consecutive, 'two tier' Bologna concept with undergraduate and graduate studies, and bachelor's and master's degrees. But the situation is not as simple as might be expected: There are quite wide differences between universities in the style of teaching and learning, and there are also large differences in the profiles: some first level degree programmes have a more theoretical profile closer in content, if not in quantity to that of the continental Europe long-cycle degrees, others are more practically oriented like the continental short cycle programmes. This two-tier concept is widespread over the world especially in Asia and in the US.

As a result of this situation the Bologna Process of European harmonization in higher engineering education requires in most countries to transfer the existing programmes into the consecutive two-tier concept. This exercise requires strong efforts especially by the universities; but, it also offers good chances to check the existing curricula, and to develop new ones.

The EFCE Working Party on Education is working on a survey on the status of the Bologna process with respect to Chemical Engineering. First results indicate that all countries actually participating in the WP are more or less active in this field. More than 280 higher education institutions in these 19 countries are offering traditional programmes in Chemical Engineering and related fields according to the models described above. Most of them have to develop new two cycle (two-tier) programmes. In 12 countries there are such new programmes in Chemical and Process Engineering already offered, in others this will be the case in 2005/2006 latest. At some places the new programmes are offered in parallel with the traditional ones. At a few others the new ones have already replaced the old ones.

How to Design New Programmes?

When looking into details the Bologna concept requires the long integrated programmes to be split into two parts of which also the first one is supposed to be relevant for the labour market. Here the first problem appears: Most of the integrated engineering courses in continental Europe today like in Germany or Switzerland consist of a basic study of nominal two years duration in which primarily mathematics, sciences and engineering basics are provided, and a branch specific study of nominal 2.5–3 years duration. Full professional qualification is achieved first after completing the entire study programme; the *Vordiplom* at the end of the basic programme is used only for performance control, and does not have any relevance to the labour market.

It might presumably be possible to displace parts of the scientific basics into later semesters (graduate study) in the sense of more advanced studies, and to provide already in the first cycle certain parts of the branch specific topics, in particular their basics. However, agreement exists to a large extent that it is not possible to achieve full professional qualification in a course of study oriented more to theory and research of only of three years duration. According to contemporary knowledge the successful completion of such a Bachelor course has still only small relevancy to the professional labour market (GVC, 2001). It is, however, the necessary prerequisite for the admission

to a further academic career, e.g., to a master course, whose level will correspond finally to the previous university diploma. Additionally it is a good starting point to change the university or to enter into a supplementary course of study as for example economics. The 'normal' end of an engineering study at a university should be in any case a second-cycle-degree.

A more difficult situation occurs in Grandes Ecoles in France: Here the students firstly have to pass 'Classes Préparatoires' for two years at selected secondary schools. They offer a basic study in selected topics, particularly mathematics and sciences. After a nation wide 'Concours d'Entrée', which acts as a sharp selection, students finally can enter into the branch specific programmes at one of the Grandes Ecoles. These programmes are of three years duration. Here the above described shift of study contents appears nearly impossible: secondary schools and Grandes Ecoles belong to different sponsors, and are linked neither geographically nor organizationally. This may be the main reason, why the Grandes Ecoles are up to now very reserved about the Bologna Process, despite the fact that France is one of its initiators.

Another problem occurs for example with the *Fachhochschulen* (Universities of Applied Sciences) in Germany: today they are offering application oriented engineering programmes of four years duration, whose trademark is among other things a practice semester which the students take in industry. Graduates of these courses are much sought after in the industry, in part even more than the graduates of the 'long cycle' courses more oriented to theory and research. Many *Fachhochschulen* are attempting now to offer Bachelor programmes, which they limit to three years by omitting particularly the practice semester and by reducing the time to work on the final thesis. The limitation is caused by the aim to save time in order to be able to offer additional second-cycle programmes with two years of duration too (the total nominal duration of study is limited to five years). In my opinion both bypass the requirements of the labour market: the graduates of the short courses are less qualified than the labour market is used to expect, and only a very small requirement exists in the field of engineering for graduates of long courses at a *Fachhochschule*.

Instead of only rearranging old courses into the Bologna scheme higher education institutions should take the opportunity to develop really new programmes. A very interesting approach with respect to Chemical Engineering can actually be observed in the US: Under the auspices of the Council for Chemical Research, with funding support from the National Science Foundation a number chemical engineers coming from several universities including MIT recently have started a project called 'Frontiers in Chemical Engineering Education'. Within this project they are trying totally to re-invent the undergraduate curriculum in Chemical Engineering totally. Without going in too much detail it can be stated, that when doing so they follow three organizing principles for a Chemical Engineering curriculum (Frontiers, 2003):

- Molecular processes—fundamental processes at the molecular level—physical, chemical, and biological
- Multiscale analysis—tools appropriate to a given length of scale (molecular dynamics, continuum equations, macroscopic averages, transient and steady state processes)

- Systems analysis and synthesis—realistic chemical engineering problems (dynamic behaviour of batch and continuous processes in nature, technology, and society)—topics include modelling and simulation, optimization, dynamics and control, feedback and recycle, financial analysis, process and product design, and plant operation.

Additionally, they define the attributes of a B.S. graduate with respect to his role as problem-solver (both analysis and synthesis activities), to his ability of life-long professional growth, and to a broader context as e.g., his social responsibility. Independent of the way how to teach, which may vary from university to university, this new concept requires a rearrangement of the whole content of a Chemical Engineering curriculum.

When looking to the overall progress of introducing Bologna type programmes of study in Europe one can say that many higher education institutions are very active in moving to comply with the new concept. But at the opposite end there are many others in several countries which have many reservations in starting to redesign old or develop new programmes.

Quality Assurance of Study Programmes

One important element of the Bologna process is to cooperate in quality assurance of study programmes. The national reports for the follow-up conference at Berlin show it is common sense that quality assurance shall be executed by specialized accreditation bodies instead of ministry employees. Some countries have had such bodies for a long time, e.g., the UK, where professional institutions like the Institution of Chemical Engineers (IChemE) are accrediting courses in their field; others have established such bodies recently. Many of these accreditation bodies are co-operating in the European Network on Quality Assurance (ENQA, 2000). Others have also joined the Washington Accord (ASIIN, 2003); here accreditation agencies specialized in the field of engineering are co-operating world-wide (Washington, 1989).

With respect to the criteria for quality assurance in higher education one has to distinguish between input oriented and output oriented methods. In the past the approval of new study programmes has mainly been based on input criteria, e.g., on curricula based examination guidelines. Two years ago at CHISA, Grant and Dickson have presented an outcomes-based approach to Chemical Engineering education at undergraduate level used in the UK. This approach is taking into account the needs of customers, e.g., students, employers of graduates, government and funding institutions for higher education, and professional institutions and accreditation agencies (Grant and Dickson, 2002).

The needs of the latter two have become especially more focused on outcomes in recent years. Today Teaching Quality Assessment (TQA) in the UK is based on benchmark statements, which are expressed in terms of attainments that could be expected by a graduate, and should be tailored specifically for each engineering discipline. This process has not yet been fully implemented throughout engineering in general or Chemical Engineering in particular. Nevertheless it will be developed further.

In the UK the actual version of IChemE's accreditation guidelines describes the minimum and distinctive core in terms of learning outcomes that a graduate from an accredited course should have acquired. Five Learning Outcomes in terms of knowledge, skills, and understanding have been defined: Mathematics, underlying science (chemistry, physics, biology) and associated engineering disciplines, Core Chemical Engineering, design, social, environmental and economic context, and Engineering Practice. The high-level learning outcome in Core Chemical Engineering may serve as an example:

'(Graduates) must be able to handle advanced problems in fluids and solids formation and processing. They must be able to apply chemical engineering methods to the analysis of complex systems within a structured approach to Safety, Health and Sustainability' (IChemE, 2001).

Also, the Accreditation Board for Engineering and Technology in the US is using an output-oriented approach when accrediting programmes of study in the field of engineering, technology, and applied science. ABET asks engineering programmes to demonstrate that their graduates have acquired eleven distinct abilities and attitudes (ABET, 2003). Finally the initiative Enhancing European Engineering Education (4E) too states that graduates should have acquired certain abilities depending of the field of study (TNE4, 2002). It is to be expected that this approach will keep on extending into Europe.

EFCE Policy on Bologna Process

On the occasion of the 4th European Congress of Chemical Engineering at Granada, the European Federation of Chemical Engineering has discussed and decided about its attitude towards the Bologna Process. The result has been published recently and can be summarized as follows (EFCE, 2003):

- EFCE welcomes and supports the idea of establishing a European Higher Education Area based on the objectives and elements of the Bologna Process in order to achieve a greater accordance in European degrees in Chemical Engineering, and to foster mobility of European Chemical Engineering students and employees.
- EFCE is willing to co-operate with all parties involved in the Bologna Process, universities, scientific societies, professional organizations, governments, European Commission, etc., to promote implementation of the principles of the Bologna (1999) and Prague (2001) Declarations.
- When doing so EFCE will take into account the merits and benefits of existing engineering education as well as of the role of Chemical Engineering in the participating countries.
- EFCE believes that a reasonable degree of diversity in the training of Chemical Engineers is desirable. Programmes leading to a degree may have different orientations, various profiles, and various orientations in order to accommodate a diversity of individual, academic and labour market needs.

The EFCE Bologna statement ends with a reference to EFCE's so called 'Core Curriculum' recommendation which will be discussed next.

WHAT WILL CHEMICAL ENGINEERING BE IN THE FUTURE?

For several years one can observe a distinct uncertainty as to what Chemical Engineering will be in the future. One has to consider too, that in many countries less than one quarter of the recent graduates go to work in the conventional chemical and petroleum industries. The majority of the graduates find employment in a wide range of industries, of which some have very recently discovered the relevance of Chemical Engineering in their operations (Prausnitz, 2001).

How should this be reflected in the development of Chemical Engineering curricula? How far will they further be based on the classical unit operations approach? What about the basics? Is Chemical Engineering changing into a computer science? Or does it need more product orientation? What about bio-process engineering?

Many authors have already dealt with this problem, e.g., Prausnitz when speaking about the changes that the Chemical Engineering profession is experiencing today and is likely to experience more intensively tomorrow. Prausnitz continues in looking for the nature of the transition when entering the twenty-first century, and comes out by requesting that Chemical Engineering needs to be reinvented if it is to survive, and additionally needs to respond to the changing social climate. Gillett asks how Chemical Engineering can adapt in a rapidly changing world without losing its identity (Gillett, 2001). Two years ago Grant and Dickson stated that the nature of the chemical and process industries is changing; this brings opportunities to diversify and to expand the applications of Chemical Engineering to new industries, new processes, and new sciences and technologies. However, there is a threat that this diversification may lead to a loss of cohesion and identity of the subject and of the profession (Grant and Dickson, 2002). Also within their very interesting attempt to reinvent the undergraduate education and training of Chemical Engineers, our colleagues in the US stated in the vision of their project *Frontiers in Chemical Engineering Education*: 'We must continue to hold a well defined core that defines the discipline and provides the basis for quantification, integration, and relevance in problem solutions' (Frontiers, 2003).

Several years ago the EFCE Working Party on Education in order to be prepared for the upcoming process of harmonizing higher education in Europe and to give an answer to the question of how to adapt without losing identity surveyed curricula in Chemical Engineering and related fields. When doing so the WP analysed a large number of programmes existing at that time in many European countries (Tracez, 1994, Pohorecki and Szebenyi, 1997). These programmes cover a wide range of different profiles as shown in Figure 2: one group has Chemical Engineering courses more or less close to the American model, which historically has been closely tied to the petrochemical industry (e.g., Belgium, Denmark, France (Grandes Ecoles), some German schools, Italy, the Netherlands, Norway, Poland, Spain, and the UK). A second group is formed by the programmes of German *Verfahrenstechnik*, the Swiss ETH, Hungary, and a few French schools; these programmes have their roots in mechanical engineering. Finally a third group is formed by the programmes of

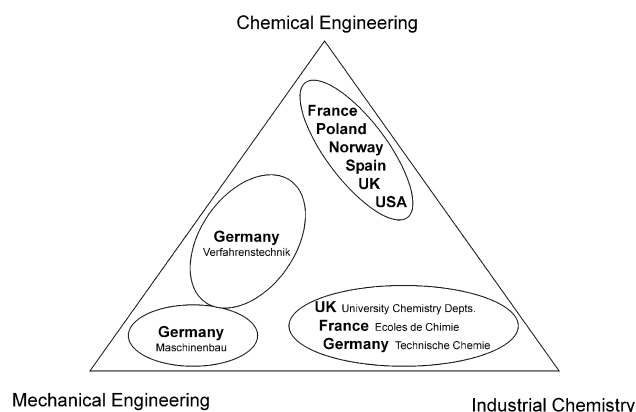


Figure 2. Curricula in Chemical Engineering and related fields (Tracez, 1994).

Technische Chemie (Germany), the French Chemistry schools and some others, which start from classical chemistry. The analysed programmes also cover a certain range of duration: they include classical long cycle (4–5 years) programmes widespread in continental Europe as well as the shorter (3–4 years) programmes in the UK. When looking at the actual Bologna discussion it has to be stated additionally that the analysed courses largely have a more scientific profile; in other words, they are more oriented to theory and research, and lead to degrees, which give access to the preparation of a doctorate (Tracez, 1995).

The final result of this exercise has been a Chemical Engineering core curriculum common to all courses. It covers approximately 50% of a total curriculum and takes about 5–7 semesters to teach (Table 2). It is based additionally on some ideas brought up by accreditation guidelines from both the UK and the US, and on personal experiences and viewpoints of the WP members coming from both academia and industry (WPE, 2000; Gillett, 2001). This core curriculum may serve as a recommendation for the further development of courses, which will be looked at as Chemical Engineering

Table 2. EFCE WP on education: recommendation for a Chemical Engineering Core Curriculum (Gillett, 2001).

| Curriculum element | Approximate content as percentage of a semester |
|-------------------------------------|---|
| <i>Basic science</i> | |
| Mathematics | 100–125 |
| Physics | 25–50 |
| Chemistry | 100–150 |
| Computer usage | 20–25 |
| <i>Engineering core</i> | |
| Thermodynamics/physical chemistry | 50–100 |
| Fluid mechanics/transport phenomena | 25–40 |
| Unit operations | 40–50 |
| Chemical reaction engineering | 20–25 |
| Plant design | 50–75 |
| Equipment/materials | 20–30 |
| Process dynamics and control | 20–25 |
| Chemical engineering laboratory | 25–50 |
| Safety and environment | 10–25 |

programmes. With respect to this recommendation it is important to note:

- The EFCE Working Party on Education believes that a reasonable degree of diversity in Chemical Engineering education is desirable. Industry is accustomed to such variety and knows how best to make use of it, but may need objective, coherent and regularly updated information on the wide range of curricula.
- In a rapidly expanding European Union, it is essential to avoid a situation in which the title ‘Chemical Engineer’ could correspond to truly different types of education and competence in different institutions outside the range shown above.
- This core curriculum should not be imposed (by what authority?) on existing programmes or to programmes to be newly developed, but should be looked at as the outcome of a consensus and as a guideline for all seeking to develop their Chemical Engineering programmes.

When elaborating its recommendation in the early 1990s, the EFCE Working Party on Education could not take into account the boundary conditions of the Bologna Process. Therefore the core curriculum has not yet been split up into a first- and second-cycle part. Therefore the WP has decided to update this recommendation in order to take into account recent developments in study organization, in curriculum accreditation principles, and in science and engineering. This updated recommendation shall be available in 2005.

CONCLUSION

To conclude I would like to highlight three statements, which may combine the issues we have dealt with:

- The lack of Chemical Engineering students in many European countries should encourage higher education institutions to make their curricula more attractive to young people taking into account the broad range of industries and fields where they can become active later, but also considering what the core of Chemical Engineering should be.
- The Bologna Process can help to foster this process of re-inventing Chemical Engineering curricula and to attract young people.
- The Education in Chemical Engineering is now ripe for re-invention (Gillett, 2001).

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