

Chemical Engineers for the 21st Century – Challenges for University Education*

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At the beginning of the 21st century, the education of chemical and process engineers is facing enormous challenges. The number of new students has dropped substantially since the early 1990s. The globalization of the world's economy has altered the working environment and the job market for chemical engineers. The areas in which chemical engineers are active now extend far beyond the boundaries of the chemical industry. As a result, universities are having to compete much more, not only for undergraduate and graduate research students but also in order to keep courses and even departments open. This paper aims to shed some light on the current situation at the universities, the changes in the conditions and job environment in the chemical engineering field, and the demands being placed on tomorrow's chemical and process engineers and on the education they receive. From an organizational point of view, it is important that the universities actively participate in and influence this ongoing process of change. In terms of course content, increasing emphasis must be placed on teaching students modern, relevant engineering knowledge and methodological and systematic skills, as well as those aspects of their education that are relevant for the ever more flexible, interdisciplinary and intercultural nature of chemical engineering work. Elements that could usefully contribute include support for study abroad programs and the provision of broad, high-quality extra-curricular studies. Despite the changes that have occurred, such as the introduction of new (bachelor and master) degrees, it is essential that the universities retain their characteristic and established profiles. At the same time, it is important to make the universities more accessible to well-qualified graduates from Germany's *Fachhochschulen* (universities of applied science).

1 A Changing Environment

Some seventy years after the first chair of process engineering was established in Germany for Emil Kirschbaum in Karlsruhe, the education of chemical and process engineers in Germany is facing major challenges. The current situation in the universities is characterized by the rapid changes occurring in the chemical engineering world. Since the beginning of the 1990s, the number of students entering university, and in particular the number enrolling to study technical disciplines, has dropped markedly. Globalization and changing technology are influencing the job and working environment of the chemical engineer. A new statutory framework has created new possibilities and has left the universities facing stiffer competition.

We begin by describing and illustrating these changes before moving on to discuss the demands that are being placed on chemical engineers and the process technology of tomorrow.

1.1 Admissions Have Fallen

Since 1990, the number of students entering German universities has decreased (Fig. 1). A slight recovery was evident at the end of the 1990s, though given demographic developments in Germany, this upturn is likely to be small in magnitude and short in duration [1,2].

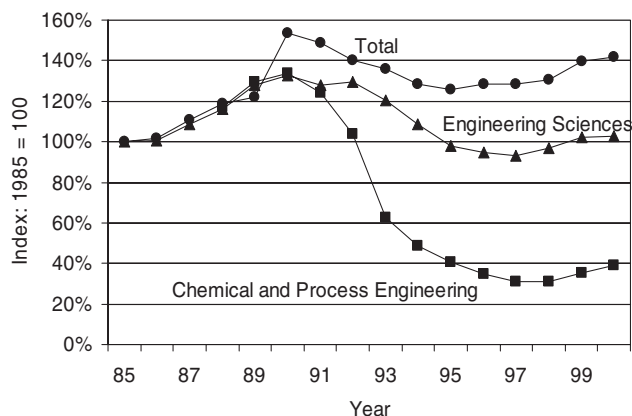


Figure 1. Trends in the number of students enrolling at institutes of higher education (Sources: German Federal Statistical Office; personal inquiries (Universities of Dortmund, Erlangen, and Karlsruhe)).

This trend is also apparent in the engineering disciplines but with one significant difference. While the total number of students entering university is now at 140% of the number entering in 1985, the number of students enrolling to study engineering is only equal to the 1985 level. That is, the relative fraction of young people deciding to study an engineering science has fallen. A worrying development for a country which is reliant on industrial performance and achievement.

A dramatic development is evident in the case of the number of students registering to study chemical and process engineering. At certain universities [3], numbers have fallen to below 40% of the numbers of students enrolling in 1985; compared to the peak in enrollments registered in 1990 numbers are now at about one quarter of that level. This downward trend would appear to have bottomed out, with

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some departments reporting a slight rise in the number of students enrolling since 1999, while others have recorded another minor fall in 2000.

There are numerous reasons for this decline and many of the explanations offered appear contradictory. Of least importance are demographic developments. The number of young people eligible to enroll as a student at a university in Germany in 1996 was 310 000, only marginally less than the figure for 1985 (320 000) [1,2]. A number of studies suggest that socio-political factors such as a decrease in the level of technology acceptance cannot be made solely responsible for this trend [4]. However, it is nowadays less common for parents or friends to advise young people to study a natural science or technical subject [5]. It is also more probable that the developments in the job market for engineers during the 1990s, which included early retirement, layoffs, and cautious recruitment practices, had a large effect [6]. Most young people have, however, lost their faith in job market forecasts [6]. An additional complicating factor affecting chemical and process engineering in particular is the fact that when it comes to deciding what to study, many school leavers have only a very limited knowledge about the work and opportunities open to a chemical and process engineer.

As it is not difficult to foresee the substantial gap that is opening up between supply and demand [7] and all those involved in the education of chemical engineers will face the challenge of having to compete for suitable students. It is especially important, that promotional work and information campaigns are directed at the children and young people in the mid and high grades of our school system.

1.2 Universities in Competition

As a direct result of the fall in student numbers, the universities are exposed to a greater degree of competition. For historical reasons, that were often anchored in regional politics, there are now some twenty universities (with about one hundred relevant professorial chairs) and around thirty *Fachhochschulen* (universities of applied science) where one can study chemical and process engineering in Germany [7]. In view of these figures, there is competition for the dwindling student numbers not only between the different types of higher education institution (university or *Fachhochschule*), but also between the individual institutions of a particular type. Chemical engineering is also in competition with other subjects for suitable students. Internationally, the German universities are competing for students from the newly industrialized countries and here Germany has competitive disadvantages that are not just related to the language. Finally, the universities are in competition with industry. It is increasingly common that a research project cannot start or cannot be continued because the potential graduate students go into industry directly after obtaining their first degree. The inevitable consequence of this situation are "adjustments"

such as the relocation of courses and professorial chairs or the merging of previously independent departments.

To survive in this climate of competition requires innovative ideas, a willingness to cooperate, an independent, unmistakable teaching and research profile and customer orientation. Given that, it is astonishing that most universities still know practically nothing about the whereabouts of former graduates.

1.3 Globalization and Technological Change Are Affecting the Engineering Profession

Market liberalization is stimulating worldwide competition. New competitors, differing customer requirements, and increasing cost pressures are all forcing companies to restructure and adapt. In the process industry a gradual shift in focus has been observable for some time, away from petrochemicals and basic chemicals and towards specialty chemicals and the life sciences. As a result areas such as batch process optimization, flexible multiproduct plants, bio-process and bioreactor technology, product design and production logistics have grown in significance but still receive barely a mention in the classical chemical engineering degree.

At the same time, ethical values and principles within society are changing as witnessed by the establishment of terms such as "sustainable development" and "responsible care". As ethical values clearly vary from region to region, only those companies who are willing and able to learn will succeed in these new markets. This means that companies must be prepared to introduce new technologies and to continuously adapt and improve their mode of operation and their organizational structure to become more decentralized, more process and team oriented and more international. Today's markets thus demand both a willingness to learn and a willingness to implement simultaneous engineering methods in which the development of a new production process and the planning and construction of a production plant proceed concurrently [8].

As a result of these developments, there will be an increasing demand for well-educated and well-trained engineers who have, in addition to academic qualifications, the ability to cope with the types of changes and developments just described [9]. In view of the short half-life time of much, particularly specialist, knowledge, there will be an increasing need for to offer life-long training and staff development programs.

1.4 A Changing Working Environment Means New Opportunities

1.4.1 Room for Experimentation:

The Federal Higher Education Framework Act of 1998

The new German Federal Higher Education Framework Act of 1998 provides an opportunity for universities to experiment with new ideas. The goal of this legislation is to

create more room for maneuver (by abolishing unnecessary regulations), more variety (universities should develop their own individual profile) and more competition (in order to arrive at the best possible solutions). Furthermore, the act aims to promote greater internationalization (in order to make German universities more attractive to foreign students) and seeks to improve the recognition of external academic achievement. The quality of research and teaching is to be safeguarded by independent assessment and accreditation. To this end, an accreditation council has been established as well as several accreditation agencies that cover various academic fields [10]. One will have to wait and see whether accreditation really does represent a mark of quality or whether the process of accreditation results in an overall lowering of standards.

1.4.2 Greater individual responsibility

At a political level there have been discussions about more independence and greater responsibility for the universities, achieved for example by the use of global budgets. Here the university would, in accordance with agreed rules, be able to allocate funds, transfer or reassign unspent money, manage and dispose of revenue and exploit the advantages that arise from first-hand knowledge and intimate acquaintance with the problems at hand [11].

Controversial aspects of these discussions include the use of selection procedures which aim to pick the most suitable applicants and thus help to reduce the number of students dropping out before they have completed their degree [12]. The introduction of university tuition fees remains an equally controversial issue.

How should the universities cope with a regulatory framework that is in such a state of flux? As the legislation will be implemented at the state level, the universities must actively participate in the discussions, putting forward their own suggestions and assuming responsibility. It is essential that the universities no longer sit back and wait in nervous anticipation of the plans being hatched within the state ministries of education [13].

1.4.3 The Introduction of Graded Bachelor and Master Degree Programs

In an effort to promote internationalization, the Federal Higher Education Framework Act includes the introduction, for a trial period, of graded courses of study leading to bachelor and master degrees in parallel to the classical courses leading to a diploma. We feel that the following comments are justified:

- It is frequently argued that these degrees are “internationally recognized”. It would be truer to say that they are typical of countries with an anglo-american educational system and are therefore well-known.

- In view of the graded qualifications that can be attained in technical disciplines in Germany (technician, Dipl.-Ing. (FH) [engineering graduate from a *Fachhochschule*], Dipl.-Ing. (TU) [engineering graduate from a (technical) university], Ph.D. in engineering science), there is, in contrast to other academic fields, little need for additional qualifications.
- A bachelor's degree can, however, simplify the exchange of students between Germany and countries with an anglo-american-type higher education system. For example, it may be easier for graduate students to come to Germany to study in a master's program or for German students to go to one of these countries to continue their education.
- In the field of chemical and process engineering there is no demand for graduates who have left university with a bachelor's degree, i.e., after having completed a short degree course covering the basics of the subject. The first degree in chemical engineering awarded by universities should be at least a master's degree that is equivalent to the “Dipl.-Ing. (TU)” qualification [14].
- There is an established and accepted difference between the qualifications Dipl.-Ing. (TU) and Dipl.-Ing. (FH). (TU: focus on fundamentals, problem-oriented approach, emphasis on scientific basis. FH: solution-oriented practical approach). The demand for both types of graduate will continue and the distinction between them must not be blurred by the new degree courses. However, there is certainly a need to make access to universities simpler for qualified graduates from a *Fachhochschule*.

In short, the new degree courses are no panacea against the shortcomings of the traditional engineering courses taught at German institutes of higher education. Notwithstanding the acknowledged high quality of these established programs, they are felt to be too one-sided, too technical and to place too great an emphasis on accumulating factual knowledge. To be relevant, the content of these courses must be revised and collaboration and cooperation between the members of the teaching staff must be improved.

2 Chemical Engineers and Process Technology in Tomorrow's World

2.1 A Variety of Skills Are in Demand

When considering the requirements that chemical engineers will need to meet in the future, it is important to bear in mind just how extensive the field in which they work has become. Thanks to a generally broad, relatively unspecialized education, chemical and process engineers are found in the chemical industry, the oil and gas industry, the plastics industry, the food industry, the pharmaceuticals industry, medical technology, environmental technology, the automotive industry, the steel industry and many others. They work with engineering contractors and with process equipment manufacturers, in multinational corporations and in medium-

sized companies, in government departments and administrative agencies, in management consultancies, in universities and in research institutes. The work they are involved in ranges from teaching and research, design, production, planning and technical management to applications technology, marketing and sales.

In the light of this broad range of activities, the following skills will be expected of the chemical and process engineers of the future, albeit with differing emphasis depending on the exact nature of the work performed:

- **Technical competence:** Teaching should focus on imparting the fundamental physico-chemical and engineering principles and selected specialist knowledge. The specialist subjects offered can form a part of the university's individual profile. What is important is that students are made aware of the complexity of the subject taught without getting lost in the details.
- **Methodological skills:** The ability to use the technical knowledge acquired to construct solutions to new problems or to find alternative solutions to familiar problems.
- **Systematic skills:** The ability to think coherently and to examine and analyze problems.
- **Social competence:** Communication skills, ability to work in a team, ability to make constructive criticism, foreign-language skills, intercultural understanding, etc.
- **Entrepreneurial skills:** the desire and skill to organize, the ability to take the initiative, to set meaningful priorities, to weigh up risks and benefits, to bring about and implement decisions, customer orientation, ability to judge what is feasible.

Given the extent to which the working environment of the chemical engineer is changing, the higher education programs in chemical and process engineering must leave graduates with the skills to work successfully in a broad range of job environments. The courses must not be overly specialized. The capacity for innovation is very often based on the ability to transfer problem solving strategies from one area to another. This requires not only knowledge of one's own subject but also knowledge of the fundamentals and methods of other disciplines. An important objective in the education of chemical engineers must remain the ability to engage in life-long learning and in interdisciplinary cooperation [15]. A modern education in engineering must promote the acquisition of the skills and abilities listed above. A well-structured program of extra-curricular studies and periods spent studying abroad can help to achieve these goals.

2.2 Developing and Improving the Contents of Chemical Engineering Degree Programs

In the invitation to the meeting to commemorate the 100th anniversary of the birth of Emil Kirschbaum, the question was posed whether Kirschbaum's approach of insisting that chemical and process engineers must first be rigorously trained in the fundamentals of engineering science, i.e. in

mechanical engineering, was still tenable. We are convinced that a thorough grounding in engineering science is indispensable for anyone wishing to work successfully as a chemical or process engineer. Whether this knowledge is gained by taking the courses that comprise the first part of a mechanical engineering degree or by studying some other subject is immaterial.

It is also worth realizing that when attempting to recruit students it can prove expedient to give modern, attractive names to chemical and process engineering degree courses (e.g. environmental process technology, bioprocess engineering, nanoprocess technology, etc.). However, it is important to ensure that these programs do indeed supply the thorough and broad-based education in engineering that is required. It is not acceptable to award a degree in engineering to those who have completed courses in a related subject area but without having to acquire a deeper understanding of engineering science. This is the situation at a number of *Fachhochschulen*, whose graduates are chemical engineers on paper but chemists in reality.

In chemical engineering, the unit operations concept should be withdrawn in favor of common fundamentals such as thermodynamics and multiphase flow systems. Deeper more specialist knowledge can still be imparted using illustrative examples as and when appropriate. It is also worth questioning the classical division into thermal and mechanical process technology – as it is, after all, the physical states of the materials involved which dominate and not the mode of energy input.

New elements that could be included:

- **Product Engineering [16–18] and nanoprocess technology [19]:** As the majority of process-engineered products on the market have properties that cannot be described in terms of simple physical quantities, there is increasing interest in understanding how complex product properties are influenced by processing parameters. However, this does not mean reverting to a traditional branch-specific approach (brewing technology, paper-making technology, etc.).
- **Environmental and life-science process engineering [20]:** Key elements here are systematic analysis and social responsibility. This is also true of other areas such as production-integrated environmental protection [21], process safety, or sustainable development [22].
- **Production logistics, batch process technology:** In view of the significance of today's batch-operated multipurpose and multiproduct plants in shortening development times and supplying the market with highly specialized products [23], the widespread opinion that only a continuous process is a good process should be reconsidered.

The universities must therefore revise and develop the courses on offer without overloading the curricula. They must find a balance between technical specialization and a broad understanding of the subject. Furthermore, universities should use this opportunity to develop their own unmistakable departmental profiles; an university does not have to offer every subject.

3 Shaping the Future

One of the major challenges facing universities is their role in shaping the future of higher education in Germany. The scope and freedom to act must be provided at the political level, but the universities must use this freedom. They must take the initiative, develop new concepts, and argue their case in the political arena.

Suitable students will need to be recruited by the universities (working together with industry). A good start has already been made [24,25].

The period of low student numbers should be used to reform and update the content and structure of the courses offered. The courage not to try and cover everything is needed. Important elements include: teaching the fundamentals, specialist knowledge taught by using illustrative examples, methodical approach, interdisciplinary teamwork, opportunity to experience cross-border, international study [26].

International cooperation should be intensified. Networks involving suitable foreign partner universities and institutes should be created and extended.

It will be necessary to educate students in the true sense of the word rather than relying on imparting factual knowledge, which has generally been emphasized up until now.

Support for appropriate further training courses and programs is needed in order to meet the demand for life-long learning.

It should be a matter of course, that the universities are involved in graduate employment and placement.

Competition in higher education must become a competition on quality!

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