Chemical Engineering Education and its Implications for Switzerland*

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Introduction

Chemical Engineering has evolved and grown rapidly since its birth in the era 1880–1900. Today it represents a large and distinct profession in many countries, e. g. U.S.A., Great Britain, Norway, the Netherlands, Japan, Australia, Canada etc. The old formula:

Chemical Engineering =
        Chemistry + Mechanical Engineering

is not correct, either in education (mostly in Universities and Technical Universities) or in industrial practice.

This paper attempts to describe the content and structure of Chemical Engineering, the outlook and attitude of the Chemical Engineer and the implications of the existence of Chemical Engineering to Swiss education and industry.

One Definition of Chemical Engineering

The American Institution of Chemical Engineers and also the Institution of Chemical Engineers, which was founded in London in 1923, support the profession and represent it to the outside world. Special mention should be made of the organisation of symposia, the application of minimum standards of knowledge and practical experience before admitting members and many topics involving education, e.g. statistics and the promotion of Chemical Engineering as a profession. A recent attempt to define Chemical Engineering, coming from the English Institution, is as follows[1]:

"Chemical Engineering is that field of activity where knowledge of the Chemical, Physical and Social Sciences is applied to situations where materials are made to undergo a required change in composition, energy content or physical condition.

Chemical Engineering is concerned with the conception, development, design and improvement of processes; the economic development, design, construction, operation and management of plant for these processes and with the utilisation of the products; and with instruction and research in these fields.

These ends are obtained in practice by the application, within a given social, economic and technological environment, of recognised procedures and methods of calculation based upon a knowledge of energy, mass and momentum transfer and physical and chemical change".

Chemical Engineering Undergraduate Education

Table 1 gives the structure of an «average» undergraduate course in England. The B.Sc.degree is awarded at the end of the fourth year and many students enter industry at this point. The numbers of B.S. and B.Sc. degrees awarded in the U.S.A. and Great Britain are now approximately 2800 and 950 each year and the number of Chemical Engineers in Great Britain grows at ca.7% each year.

Table 1. *Approximate Content of English Chemical Engineering Courses*

Year 1 (School)
  Inorganic, Organic and Elementary Physical Chemistry.
  Mathematics and Applied Mathematics.
  General Physics.

Year 2
  Inorganic and Organic Chemistry.
  Physical Chemistry (Thermodynamics).
  Mathematics.
  Electricity and Electronics.
  Hydrodynamics.
  Chemical Engineering (Mass and Energy Balances etc.).
  General Engineering (e.g.Mechanics).

Year 3
  Physical Chemistry (Thermodynamics, Kinetics, Surface Phenomena).
  Mathematics and Statistics (with Computing).
  Unit Operations.
  Transport Phenomena (Hydrodynamics, Heat Transport and Diffusion).
  Materials Science and Technology.

Year 4
  Chemical Reaction Engineering.
  Transport Phenomena.
  Economics and Planning.
  Process Dynamics and Control.
  Unit Operations.
  Research or Design or Industrial Project.
  Free choice of special topics.

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* Vortrag in der Chemischen Gesellschaft Zürich, 18. Dezember 1968.
[1] E.S.Sellers, *Profile for the Future*, European Federation of Chemical Engineering, Conference on Chemical Engineering Education, Cambridge (G.B.), July 1968.
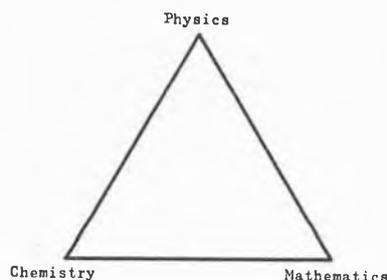
Fig. 1. Triangular Diagram of basic subjects from which new subjects may be synthesised

It is clear that Chemical Engineering education is based upon the three important subjects Chemistry, Mathematics and Physics. In terms of a triangular diagram (Fig. 1), the main divisions of Engineering (Mechanical, Civil and Electrical) are built up along the Physics-Mathematics side of the triangle; Chemistry (and especially Synthetic Chemistry) is built up mainly near the corner Chemistry, whilst Chemical Engineering is represented by mixtures inside the triangle. However different compositions are synthesised in different countries and different Universities, so that, like Chemistry, Chemical Engineering education possesses natural variations. These are considered later.

It is impossible in a short space to describe each subject; details may be found elsewhere[2,3]. Three areas, which are more specific to Chemical Engineering, will however be briefly outlined.

Separation Processes

The ratio of the capital cost of plant for separation, isolation and purification to the plant need for chemical reactions is ca. 3 to 1 in the large scale production of organic chemicals from petroleum. The separation processes are numerous and apparently diverse, including, for example, various forms of distillation (rectification, azeotropic and extractive distillation), gas absorption, liquid-liquid extraction, adsorption, ion exchange, solid-liquid extraction, crystallisation, drying, dialysis and osmosis. These separation processes are clearly all familiar to the Chemist. The Chemical Engineer however is usually scrutinising the process in more detail and especially more quantitatively. The yield, efficiency, output and economics are vital factores which he must consider. The Chemical Engineer will also know that the conditions of temperature, pressure, concentration, pH etc. used by the Research Chemist are not necessarily the best conditions for the full scale process. He must therefore critically examine[4] all aspects of a process. For

[2] The Institution of Chemical Engineers (London), *Scheme for a Degree Course in Chemical Engineering* (1965).
[3] The Careers Research and Advisory Centre, Cambridge (G.B.), *Chem. Eng. 1967.*
[4] D. M. ELLIOTT and J. M. OWEN, Critical Examination in Process Design, *The Chemical Engineer*, CE 377 (November 1968).

example, batch distillation at atmospheric pressure has been used to purify certain intermediates in a process. The Chemical Engineer who is developing this process, must first consider the complete process and ask whether it is necessary and economical to purify (by any method) at this stage. If purification is needed, the question is why use batch distillation at atmospheric pressure. A continuous operation at perhaps another pressure should be considered together with modifications like azeotropic and extractive distillation. Finally the Chemical Engineer must decide whether he has the necessary data to specify the separation process which will be used in the large scale manufacturing plant. If not, new experiments must be designed and conducted. Many standard distillation calculations have been programmed for the digital computer. It is probably true to say that the commonest rate determining step in the rational and economical specification of a distillation column is the determination of phase equilibria and not in the methods of calculating its diameter, height etc.

The scientific knowledge needed to understand separation processes is:

a) thermodynamics, especially of non-ideal mixtures;
b) heat transmission;
c) fluid mechanics;
d) diffusion.

Thermodynamics and phase equilibria guide the selection of the type of process and determine the size (number of theoretical plates) of column needed for distillation under ideal conditions. Heat transmission and diffusion rates, together with a knowledge of bubble sizes (fluid mechanics) help to translate the ideal column into a practical one. Fluid mechanics also controls the diameter of the column, which must be large enough to allow the countercurrent flow of liquid and vapour. Economic considerations must naturally be added to this scientific knowledge. Some examples of the complexity which exists in closely integrated separation processes include:

a) the low temperature distillations needed to purify methane, acetylene, ethylene, propylene etc. after the cracking of oil;
b) the extractive distillation stages used to purify butadiene and also to purify the butenes after the cracking of butanes.

Chemical Reaction Engineering

Our understanding of the macrokinetics and mechanisms of chemical reactions when these are conducted under industrial conditions (scale, impurities etc). has greatly advanced during the last ten years, the initiative for this expansion coming firstly from Europe. In particular the relationships between the chemical kinetics and the physical kinetics (transfer rates of momentum, energy

and mass) have formed the basis for much of this development.

Typical situations where chemical and physical factors interact in industrial chemical reactors include temperature control and rates of heat removal (or supply). A very simple example concerns the time needed to raise the temperature of a batch reactor to the normal working temperature. This can often be conducted in a few minutes in laboratory scale apparatus, whilst perhaps one hour is necessary in an industrial reactor. The extension of the time is caused by a lower heat transfer rate and especially by a lower heat transfer area per unit volume of liquid as the size increases. Not only is time wasted, but also the progress of the reaction is more difficult to follow quantitatively, because of the large effect of the varying temperature on the rate constant. A recent simple application of non-isothermal chemical kinetics to the sterilisation of antibiotic fermentation vessels illustrates the additional complexity of technical calculations[5].

Large axial and radial temperature gradients in tubular reactors which contain catalyst particles are well known. Even in a relatively small diameter tube, say 5 cm, the difference in temperature between the axis and the tube wall can be 50 to 250°C, especially for highly exothermic reactions, e.g. oxidations. These large differences are caused by the low effective thermal conductivity of catalyst and gas. They result in damage to the catalyst and loss of yield for reactions of the type $A \rightarrow B \rightarrow C$ or $A + E \rightarrow B$ simultaneously with $A + E \rightarrow D$, where B is the desired product. (A more complete introduction to the general principles of optimising the yield is given by DENBIGH[6]). Excessive temperatures and losses of yield may be avoided by using a more expensive form of reactor containing many smaller tubes, by decreasing the degree of conversion and then recycling unreacted material, so that it flows again through the reactor—this can sometimes also be expensive—or by contacting gas and solid in another form of reactor, e.g. a fluidised bed, where heat transfer is faster.

Variations of temperature in the axial direction may sometimes be partially limited with a non-adiabatic reactor. For a reversible reaction which is exothermic in the desired direction, e.g. synthesis of ammonia from H_2 and N_2, it was seen 30 years ago that there existed an optimum variation of temperature along a reactor, rather than an optimum single temperature. For this type of reaction mechanism, a high temperature is first used to give maximum reaction rate when the conversion is small. As the conversion rises, the temperature must fall to depress the rate of the backward reaction, relative to the forward reaction (Fig.2). This essentially
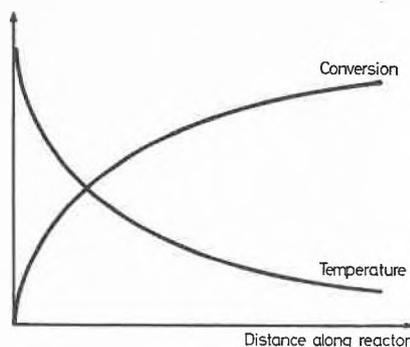
⁵ J.W.RICHARDS, Rapid Calculations for Heat Sterilisation, *Brit. Chem. Eng. 10* (1965) 166.
⁶ K.G.DENBIGH, *Chemical Reactor Theory: An Introduction*, Cambridge University Press (1965).

Fig. 2. Temperature and concentration profiles in a tubular reactor for optimisation of a reversible, exothermic reaction

simple idea has since been extended to other more complex reactions.

The mixing of fluids in a reactor is a second large area where the physical processes of stirring (momentum transport) and diffusion influence the rate and course of chemical reactions. As an example consider a batch polycondensation reaction used to procedure a polyester or a polyamide. The agitator operates initially in a low viscosity environment, where the reaction rate is chemically controlled and influenced by the catalyst concentration. In the later stages however the viscosity of the molten polymer rises to some thousands of poises; the rate is predominantly diffusion controlled, and the condensation product (water or an alcohol) must be irreversibly removed. The design and testing of an agitator, which is efficient over the wide range of viscosities existing in a batch process, is a difficult, but not insoluble problem. Other examples of the importance of mixing occur in the very broad field of heterogeneous reactions, e.g. nitration, sulphonation, oxidation (including aerobic fermentation) and chlorination. In all cases gas bubbles or liquid droplets must be formed to increase the rate of diffusion into the liquid and therefore increase the reaction rate. Not all these reactions are diffusion controlled under industrial conditions, but in most cases the geometry of the agitator controls the flow pattern and the turbulence, which in turn control bubble sizes and rates of gas absorption and reaction. As a final example of mixing effects, Figure 3 shows a) early mixing of two liquids, followed by a tubular reactor, and b) first a tubular reactor, followed by a stirred reactor, together with the concentration profiles for steady state reaction. For a single step, first order reaction, the total conversion is the same for both reactor systems. For a simple reaction having an order > 1, system b) has a higher conversion than a), although the dynamic response (concentration versus time) for a non-reactive substance is the same for both. Considering now a more complex reaction mechanism $2A \rightarrow A_2$ and $A + C \rightarrow B$, where B is the desired product, the second reaction can be promoted relative to the first by system a). Although Figure 3 shows two reactors, one of which
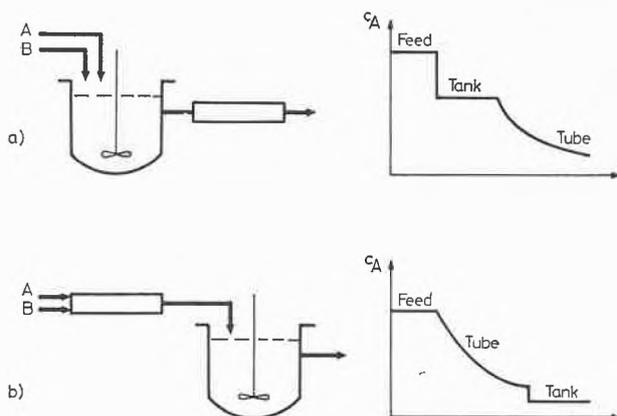
Fig. 3. Influence of order of mixing on concentration profiles

is well mixed and one of which is a tube, it is possible to find these two types of flow pattern inside one stirred tank. This happens when the stirring rate is so low or the viscosity is so high that good mixing cannot be obtained. Not only are the yield and selectivity of reactions influenced by the order of mixing, but it is also possible to vary the distribution of molecular weight for a homopolymerisation, of composition for a copolymersisation and of particle size for a crystallisation.

Two final topics should be briefly mentioned: dynamic conditions and optimisation. All processes, including "steady state" processes, are subjected to disturbances and it is usually important that the process returns to a stable condition. Thus the study of the nature of the disturbances and the characteristics of the process when it is disturbed form an important meeting point for the Chemical Engineer and the specialist in Process Control. Figure 4 refers to a given output of product, so that as the number of reactors, each of given size, increases the yield rises and the raw materials cost falls. This is however ultimately balanced by the rising cost of the reactors. Real cases are normally much more complex involving many independent variables and also some constraints, e.g. safe working temperatures. However
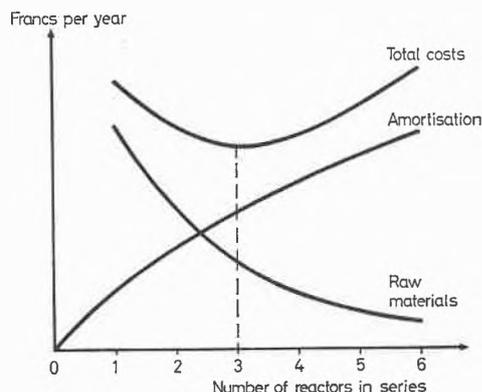

Fig. 4. One parameter optimisation for a cascade of stirred tank reactors (optimum = 3 reactors)

considerable progress has been made in solving complex optimisations, using a digital computer.

These few examples show that the Chemical Reaction Engineer must integrate a knowledge of Chemistry, especially Thermodynamics, Kinetics and Reaction Mechanisms, and of Economics with his own special knowledge of the characteristics of reactors. He starts from a generalised point of view, which is more a methodology than a number of facts, and then applies this to the specific reactions which must be scaled up and exploited commercially.

Process Development and Planning

Enough has now been written to show that the Chemical Engineer has close scientific interests with the Chemist, but that his approach to problems is sufficiently different from the outlook of the Chemist for the Chemical Engineer to have an independent existence. He is not in principle a Chemist, whereas the Industrial or Applied Chemist—and the definition of these terms is seriously lacking in precision—is in principle a Chemist.

Process Development is a complex activity needing the skills of many people, e.g. Mechanical Engineers, Economists specialising in Market Research, Control Engineers, Physicists and Mathematicians. However the translation of a chemical discovery into an economic chemical process is predominantly the responsibility of the Chemist and the Chemical Engineer. At least 25% of the Chemical Engineers in British industry work on Process Development[3]. Although it is sometimes said that the contribution of the Chemical Engineer is very small in the early stages of the life of a new process and that his activity reaches a maximum later, it is vital that the Chemical Engineer should be present in the early stages. He must understand and cooperate in the work of the Chemist so that the critical points which will occur in later development are forseen. Valuable development time can be saved if the Chemical Engineer is preparing proposals for the final process and is also defining the work of the Chemist before the Chemist has completed his study of the purely chemical aspects. The Chemical Engineer must anticipate scale-up problems, but perhaps his largest contribution is that he will see the process as a whole, starting from raw materials and ending with a saleable product. Only by taking this broad view can he identify the fastest route to the final process and evaluate the costs (in money, men and materials) of alternative courses of action.

Two techniques which aid the organisation of complex projects—critical analysis and simulation—will be briefly described. Critical analysis follows a systematic series of questions and answers, in which all possibilities are first postulated and then criticised[4,7]. A few of the

[7] F. R. BRADBURY, L. M. ROSE and C. W. SUCKLING, Trends in Process Development, *Chemistry in Britain 1968* (November).
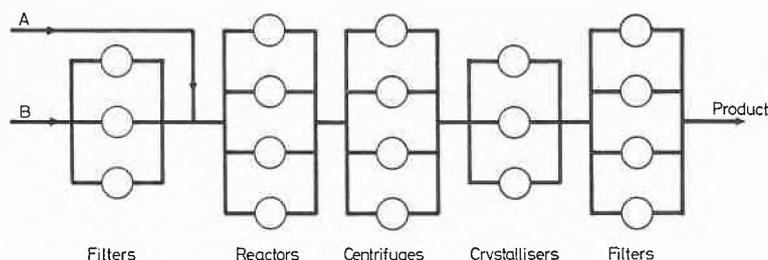
Fig. 5. A typical multistage batch chemical plant

Table 2. *Planning*

1. What is best method to operate the existing plant?
   Yield? Output? Efficient use of labour and services?
2. What is the best modification to the existing plant?
   More units? More maintenance? Less variability?
3. Can better design and construction programmes be used for future plants?
   How is construction programme influenced by market forecasts?
4. Can better plant be used in the future?
   New reactor system? New separation plant?
5. When should production be expanded? And by how much? And where? Market forecasts? Variation of capital and operating costs with size of plant? Type of economic criterion, e.g. present worth?
6. Will different chemical routes become more attractive in the future?
   Change the sequence of stages?

questions arising when one considers the expanding market for an existing product are shown in Table 2. Simulation refers to the calculation of the performance of a component of a plant or indeed of the whole plant, as opposed to the direct measurement of this performance. An example is the calculation or the output of a multistage batch chemical plant. Naturally it is not necessary to calculate this output under normal operating conditions—then it can be measured—but if it is proposed to change some of these conditions, a simulation calculation can be much cheaper than direct experimentation with a large plant. This simulation is not simple for a multistage batch plant because of the general complexity of the various flow paths through the network and of the variability of processing times in each stage, e.g. a reaction time may be distributed with a standard deviation of 15 minutes about its mean value of 3 hours. The existence of these statistical variations in a complex network (Figure 5) make it essential to simulate the plant on a digital computer and then to compute the average output over many hundreds of reactions by a Monte Carlo method. This shows which stage in the whole plant is rate determining and so limiting the output, and also to what extent the variability of processing times causes a loss of output. This information could not be obtained without the aid of a computer and today several computer programmes are in existence for this type of calculation.

The Chemical Industry and Chemical Engineering Education

In addition to their strong support and interest in research in Chemical Engineering (financial grants to students and for the purchase of special instruments and equipment; loan of equipment etc.) the Chemical and Process Industries also in general cooperate in the undergraduate educational programme. Industrial experience for students (and also sometimes for their teachers) can be of various types. Its duration ranges from 6 to 8 weeks in the summer vacation, to a 6 month or a 12 month period in various departments (Development, Production etc.) of a large company. The M.I.T. School of Chemical Engineering Practice includes ca. 4 months in industry. It should be emphasised that in all cases the work done by the student is not part of the normal routine work of industry, but that it is project work which is carefully planned between the University and industry so that it is of real educational value. It has technical, economic and general organisational aspects and may be performed in a small group of 2 to 5 students.

The Chemical Industry also expresses its views on Chemical Engineering Education to the Universities and in the U.S.A. and in Great Britain these views often flow through meetings of the professional Institutions. Table 3[8] shows the eight subjects which a Chemical Engineer in industry used most frequently in 1960:

Table 3. *Most frequently used Subjects in Industry (G.B.) (1960)*

Unit Operations (especially Separation Processes)
Chemistry (especially Physical Chemistry)
Hydrodynamics
Heat Transfer
Instrumentation and Process Control
Economics
Report writing
Materials Technology
(Not in order of importance)

The distribution five years later was the same[9]. Table 4 looks ahead and suggests the core subjects which should be taught today in order to prepare a student for his professional work in industry.

[8] R.E. JOHNSTONE, A Survey of Chemical Engineering and Practice, *Trans. Inst. Chem. Eng. 39* (1961) 263.
[9] R.E. JOHNSTONE, A Second Survey of Chemical Engineering Education and Practice, *The Chemical Engineer, CE 7* (January 1966).

Table 4. *Suggested Core Subjects*

1. Physical properties of materials, particularly related to the environment of use.
2. Descriptive inorganic and organic chemistry.
3. Heat, mass and momentum transfer.
4. Classical and chemical thermodynamics.
5. Rate processes applied in the broadest sense.
6. Modern ideas of economic evaluation, relating resources and value in design, operation, investment etc.
7. Mathematical and computer techniques.
8. Process control and optimisation.
9. Overall integration in any problem through the systems approach, including study of system concepts and human behaviour.

Research and Graduate Courses in Chemical Engineering

Tables 5, 6, 7 and 8 give a rapid superficial picture of the topics included in Master Degree programmes and for research in two Universities in the U.S.A., one in Canada and one in England.

Table 5. *Graduate Program:*
Chemical Engineering, Berkeley, California (Faculty = 18 Professors)

M. S. Degree:

Separation Processes for Multicomponent Mixtures
Phase Equilibria
Diffusional Operations
Applied Kinetics
Chemical Reactor Design
Applied Mathematics
Chemical Process Dynamics
Electrochemical Engineering
Transport Phenomena
Computational Methods
Nuclear Chemical Engineering
Cryogenic Engineering
Petroleum Processing
Research Project

Research Program:

Same subjects as above.

At Berkeley and Imperial College, London, Chemical Engineering is closely associated with Chemistry and with Chemical Technology respectively. At M.I.T. and Waterloo, Chemical Engineering is independent, but it is clear in all four cases that Chemical Engineering teaching and research contain a real contribution of Chemistry, rather than of Mechanical Engineering. It is also clear however that these post-graduate activities are not only in Applied Chemistry, but they cover a wider spectrum of topics. The unifying theme is that all are relevant to the development and design of process which change the state and/or composition of materials, and with the plant in which these changes occur. Specialisation is clearly shown at the post-graduate stage, whereas specialisation and the teaching of specific technologies are largely excluded from the undergraduate study. The

Table 6. *Graduate Courses:*
Chemical Engineering, M.I.T., Cambridge (Faculty = 27 Professors)

M.S. in Chemical Engineering	Entry Requirements =
M.S. in Chemical Engineering Practice	Physical and Organic
M.S. in Materials Engineering	Chemistry

1. *Engineering Operations*
   Thermodynamics
   Distillation
   Absorption and Extraction
   Heat Transmission and Combustion
   Hydrodynamics
   Applied Mathematics

2. *Applied Chemistry*
   Industrial Chemistry
   Ion Exchange
   Catalysis
   Advanced Thermodynamics
   Applied Kinetics
   Chemical Engineering in Medicine

3. *Materials Science and Engineering*
   Physics and Chemistry of Surfaces and Colloid Science
   Structure and Properties of Polymers
   Molecular Interactions in Polymeric Microstructures
   Physical Chemistry of Polymers
   Synthetic Chemistry of Polymers

4. *Fuel Engineering*
   By selection of subjects in 1. and 2. and by special seminars.

Table 7. *Research Interests:*
Chemical Engineering, Waterloo, Canada (Faculty = 25 Professors)

Chemistry:
Reaction Mechanisms, Kinetics, Thermodynamics, Catalysis, Reactor Design.
Photochemical and Electrochemical Oxidations.
Chemical Treatment of Effluents.
The Engineering of Biochemical Processes.
Ion Exchange.
Crystallisation.
Polymer Properties, Thermodynamics of Solutions, Physical Properties, Polymerisation, Graft Copolymers, Radiation and Emulsion Polymerisation.

Applied Mathematics:
Process Dynamics and Control.
System Analysis.
Optimal Design and Control of Reactors.
Stochastic Processes.

Process Metallurgy:
Molten Salt Electrometallurgy.
Metals Reduction Processes.
Hydrometallurgy.
Heat Transfer and High Temperature Processes.

Transport Phenomena:
Transport Properties.
Diffusion (with applications to Drying and Mixing).
Hydrodynamics (with applications to Mixing).
Flow through Porous Media.
Properties of Membranes.
Dynamics of Fluids and Particles (with applications to Fluidisation).
Two Phase Flow.
Diffusion in Reacting Mixtures.

Table 8. *Graduate Program:*
Chemical Engineering and Chemical Technology, Imperial
College, London (Faculty = 37 Professors and Lecturers)

M. S. Degrees:
1. Advanced Chemical Engineering:
   Mass Transfer Operations.
   Reactor Optimisation and Theory of Chemical Processes.
   Fluid and Particle Mechanics and Heat Transfer.
2. Chemical Physics and its Applications to Technology:
   Chemical Physics.
   Fuel Technology and Combustion.
   Silicate and Ceramic Technology.
3. Industrial Safety.
4. Nuclear Chemical Technology.

Research Groups:
   Transport Phenomena, Transport Properties.
   Separation Processes.
   Optimisation.
   Combustion and Fuel Technology.
   Properties of Solids.
   Interfacial Phenomena.
   Nuclear Technology,
   etc.

professors teaching in these large Chemical Engineering departments come from Chemical Engineering, Chemistry, Physics, Mechanical Engineering and other subjects. In the period 1950–1960, 9% of all B.S. degrees in Engineering were in Chemical Engineering, but 25% of all Ph.D. degrees were in Chemical Engineering. The orientation towards research in Chemical Engineering is even stronger today.

Diversification in Chemical Engineering

It has been convenient up to this point to write of Chemical Engineering as a single subject, but this is no more true than it is for, say, Chemistry and Physics. In practice these names are convenient to describe a general area, but significant overlap and interaction can be found between subjects when a deeper analysis is made. In the particular field of Chemical Engineering, no significant specialisation in the B.S. and B.Sc. courses is found in the U.S.A. and Great Britain. Unlike the older courses in Chemical Technology, Chemical Engineering (which has superceeded them) is not directed towards specific types of manufacture. Thus, for example, the University of A does not bias its undergraduate course significantly towards the Petroleum Industry, whilst B considers only the Dyestuffs Industry. Rather the generalised methodological approach is applied to examples drawn from many industries. Specialisation is evident however in post graduate work, as explained before.

Some diversification can however be found in undergraduate courses and it is derived from two sources:

a) the balance between Chemistry and Engineering;
b) the balance between analytical, theoretical studies and more practically orientated studies.

The Chemistry-Engineering equilibrium exists partly for historical reasons and partly, because of the different functions of Chemical Engineers in industry. The historical reasons are stronger in Europe and more particularly in the German speaking countries. The gap which existed in Physical and Engineering knowledge between the Technical Chemist and the Mechanical Engineer perhaps lead the Engineer to move slightly towards the direction of Chemistry. It certainly allowed him to move into the area of physical changes and the Unit Operations, e.g. separation processes. However the knowledge of the chemical properties of substances and especially of chemical reactions, coupled with some practical, laboratory experience which the average Chemical Engineer has is greater than that of the average Verfahrensingenieur. Table 9 shows a figure of 15% for Chemistry recommended by the Verfahrenstechnische Gesellschaft (VDI), but it appears in several German Universities and Technischen Hochschulen that in practice less Chemistry is included[10] and ca. 10% is a normal maximum.

Table 9. *Distribution of Lecture Time (%) between various groups of subjects*

	U.S.A. (average)	VTG im VDI	I. Chem. E. (Construction)	I. Chem. E. (Process)
Mathematics and Physics	21	20	20	19
Chemistry	21	15	15	25
General Engineering	10	20	25	10
Chemical Engineering	28	30	34	40
Diverse subjects	20	15	6	6
	100	100	100	100

This is small compared to the American and English figures which fall in the range 15 to 25%, but of course the Verfahrensingenieur is stronger in Mechanics, Electrical Engineering, and the Design and Construction of Machinery etc. (Apparatebau). In the U.S.A. and Great Britain these design and constructional aspects of chemical plant are often executed by Mechanical Engineers after discussions with Chemical Engineers and probably also Chemists. This frees the Chemical Engineers to concentrate more in the direction of the development, design, operation, control and optimisation of complete chemical processes in collaboration with the Chemist. Nevertheless four years ago the Institution of Chemical Engineers[2] published proposals for two forms of Chemical Engineer and it is this which is summarised in Table 9. These proposals have not yet been widely adopted and the «average» English Chemical Engineer receives today an undergraduate education which is approximately the mean of the two colums of figures. The figures in Table 9 for the U.S.A. come from an interesting paper which also traces the evolution of Chemical Engineering education over the past sixty

[10] H. BLENKE and K. DIALER, *Chemical Engineering Education in the Federal Republic of Germany* (see the Conference of Ref.[1]).

years[11]. Two final points should be mentioned about the Chemistry-Engineering equilibrium in undergraduate education. The first is that, although in England, the distribution of the ca. 5000 Chemical Engineers between industries is known, the functional distribution is harder to define. It is probable that for every 1 Chemical Engineer in the constructional function, there are 2 to 3 in the process function. Finally the Chemical Engineer will find his professional life in industry and therefore any Chemical Engineering course should reflect the industrial and social environment in which the student studies. To take a rather extreme example, research in Chemical Engineering in an underdeveloped country may well be directed at the exploitation of natural resources, e.g. timber, oils and fats and food preservation.

The balance between theoretical and practical studies influences not only the educations programmes for Chemical Engineers, but also those for many other scientists and engineers. There has been a tendency, e.g. in the U.S.A., for overemphasis of theoretical studies (e.g. mathematical modelling) and a corresponding counterattack[11]. The paper *Science Ain't Everything*[12] is a stimulating discussion of a problem which perhaps never can be solved so that everyone is satisfied. Some suggestions for reaching a comprise are:

1. Limitation of lectures to a maximum of 10 to 14 hours per week.
2. Encouragement of the problem solving attitude through examples classes.
3. Preservation of laboratory experiments and projects, together with opportunities for discussion of the results, features of the apparatus and methodology.
4. Opportunities for periods of work in industry (as described earlier).
5. Adoption of the following teaching methods at least in the higher semesters:
   a) short description of the real situation;
   b) careful abstraction of the aspects of the real situation which will be treated theoretically (assumptions to be noted);
   c) formal analytical treatment;
   d) interpretation of treatment and application to real situation (it is not sufficient to give only stage c) or even stages c) and d);
6. Opportunities for critical discussion of scientific topics between students and their teachers and including, on occasion, visitors from industry.

Chemical Engineering Education in Switzerland

Chemical Engineering Education does not exist in Switzerland in the sense it that is described for the U.S.A., Great Britain etc. in this paper. In the ETH, Zürich, courses for the Dipl.Ingenieur-Chemiker and the

[11] O.A.HOUGEN, Chemical Engineering Education in the U.S.A., *The Chemical Engineer*, CE 222 (September 1965).
[12] W.R.MARSHALL, Science Ain't Everything, *Chem. Eng. Progr. 60* (1964) 17.

Dipl.Maschinen-Ingenieur include certain aspects of Chemical Engineering and of Verfahrenstechnik. The content of the Chemistry Diploma course in ÉPUL, Lausanne, is even smaller.

It is the writer's opinion that Swiss needs could be satisfied by the Chemist–Chemical Engineer–Mechanical Engineer structure. Just as the higher semesters of study for the Chemist and Mechanical Engineer allow some free choice to the student, so also the student of Chemical Engineering should have possibilities to study with more emphasis towards chemical processes or towards the construction of equipment or indeed in one or two other directions. The composition of the mixture provided for the student of chemical processes is still under intensive discussion, but it is sufficiently well defined to give its provisional form in Table 10:

Table 10. *Programm für Chemie-Ingenieur-Wesen an der* ETH*

Mathematik, Statistik, Optimierung, Computing	18%	} 25%	(18%)
Grundlagen in Physik	7%		
Anorganische, organische, industrielle Chemie	15%	} 27%	(30%)
Physikalische Chemie	12%		
Konstruktion und Werkstoffe	5%	} 9%	(5%)
Messung, Regelung, Kontrolle	4%		
Einheitsoperationen, Transportphänomene, Planning and Systems, Reaktionstechnik	25%	} 38%	(47%)
Diplomarbeit	13%		
Diverse		1%	(–)
		100%	(100%)

* Zahlen in () für *totale* Zeit, z.B. Vorlesungen, Übungen, Repetitoria und Praktikum.

Briefly summarising some of the remarks made earlier about the functions of the Chemist and the Chemical Engineer: The Chemist accumulates knowledge in the laboratory, which is his «home», using predominantly experimental methods. He is often concerned with new syntheses—"the art of discovery"—physical and chemical properties of substances and molecular structure. The Chemical Engineer is more at home in the Process Development and Pilot Plant Laboratory and in the full scale Production Plant. He accumulates knowledge about the characteristics of reactors and chemical plants in general and he applies his methods to complete chemical process, especially to the efficient use of materials, energy, time and people and to the generally quantitative and economic aspects. In industry many activities are complex and need the combined efforts of several specialists. I believe that the combination of the predominantly analytical thinking and systems approach of the Chemical Engineer with the predominantly creative thinking of the Chemist is powerful and effective in the chemical industry.