Structuring a Chemical Engineering Curriculum for the Globalized Era

K. C. Khilar[1], K. P. Madhavan[2], A. Kudchadkar[1] and P. Ray[3]

1. Institute of Petroleum Technology, Gandhinagar
2. Indian Institute Of Technology, Bombay
3. Department of Chemical Engineering, Calcutta University

A Brief Review:

Establishment of Chemical Engineering as an independent discipline took a long time- from the eighteenth century to the beginning of twentieth century, and its search for "self" or "identification" continued for an additional couple of decades. As is well known, the chemical engineer had to establish himself – first by proclaiming his distinct identity and then winning recognition from the engineering, scientific and industrial community. And subsequently he had to reinvent himself - that is redefine his field of expertise, knowledge and application several times – or rather continuously over the last hundred years. Historically the "modern" chemical engineering became recognizable only in 1950's and possibly1960 's but the process of redefinition or evolution has continued unabated. The history of development of Chemical Engineering courses from Industrial Chemistry to present days "multiscale" through phases of "unit operations" , "chemical engineering science" is well known.

Chemical Engineers as a group seem to be greatly concerned with self identification and as a natural consequence are also highly concerned about the training to be imparted to the prospective entrant. Thus it is surprising that during the last 40 to 50 years, the chemical engineering curriculum has retained a basic form and structure, which are accepted more or less over the entire world – something pointed out by Ruthven more than 10 years ago.

It is however true that, while the basic form has been retained, the details - courses, approach, methodology and emphasis have shifted considerably. And in the last two decades there has been sufficient growth of the field to merit some reconsideration. New areas like biotechnology, nanotechnology have emerged, demand for speciality chemicals and products is increasing rapidly, globalization has increased competition in business environment, communities have become more conscious about environment.

Boundaries of Chemical Engineering have been expanding in response to the advances in basic sciences, computational methods and technology and new societal demands like energy, environment, sustainability and in the last decade the expansion has accelerated. Changes in world political, economic and business situation and social awareness have also contributed directly or indirectly to these changes.

Chemical Engineers all over the world have certainly responded by conducting discussions, seminars, workshops and a host of recommendations have already been made- and some already are in the process of implementation.

In the US, the ABET system is primarily concerned with the quality of the training/ education imparted- and this does involve the content and curriculum- usually decided by experts, professionals and professional societies of the specific field. The accreditation method requires educational goals to be set for courses and the results/ degree of goal attainment evaluated. The method also emphasize skills in application and analysis.
The curricula and course content in the US is decided by the institute/ school – but it does follow a guideline evolving out of meetings, workshops, seminars participated by institutes, professionals and societies- like the AIChE-MIT workshop.

In Europe, the EFCE, based on the Bologna convention has made recommendations for the two cycle course- a 3 yr first degree and a 2 yr second degree course. A major difference is the duration- the first

degree- apparently bachelors- will require 3 yrs in contrast to 4 yrs in the US or India. But it appears that Bologna convention would make the completion of second cycle- that is Masters degree -the minimum qualification for a professional engineer. Thus it may be effectively going in for a 5 yr training.
The time scale is certainly important as many new topics/ subjects have been recommended for inclusion in the curriculum along with additional industry training.

In India, the IIChE had taken the initiative and had formulated a course/ curriculum guideline (CEEDC- Chemical Engineering Education Development Center) . The AICTE- the official accrediting body- has effectively adopted this guideline. There has also been several workshops/ seminars discussing the issue. Gandhi and Kumar in a recent paper have put forward a recommendation.

It is of interest but not surprising to note that the recommendations/ proposals of these workshop/ symposia are quite similar in broad content. They all generally agree that
i) the courses must be built around core chemical engineering , there being substantial agreement as to what the "core subjects" are.
ii) basic sciences- physics, chemistry , mathematical methods and multiscale analysis need to be emphasized, and some bioscience need to be introduced.
iii) emphasis must shift from " data/ information accumulation" (that is "memorize") to " analyze and apply", with stress on innovation and adaptation.
iv) sufficient flexibility to allow electives for introduction to different branches/ areas particularly the new and emerging ones should be incorporated.
v) there should be some courses for training in management, communication skills, enterpreneurship, social and environmental impact, sustainability
vi) industry apprenticeship and practical/ experimental work should be stressed/ increased
vii) there should be an evaluation of the quality of the education process itself

It is apparent that there has already been a great deal of discussion and a general convergence of opinion has been achieved, and now it is necessary to look at implementation rather than initiate further discussion. It appears therefore that there is little point in rediscussing the basic tenets- “absorb, assimilate, adapt and apply”- though what is to be included and what should be left out and how it is to be imparted will remain debatable forever. These aspects have also been addressed in many of the papers and presentations on many occasions including the present meeting(???) but still there seem to be a few aspects which have not yet attracted a detailed scrutiny.

Developments in Chemical Engineering

One of the major reasons for the proposals for curriculum modification is the rapid extension of boundaries of Chemical Engineering- and one aspect of this expansion is creation of new fields like energy, environment, biomedical technologies, atmospheric sciences. Now whenever an established field expands and sprouts out new areas, the field consolidates itself primarily in two different ways. The first one is broadly followed by fields of science, the second primarily by engineering. It does not however mean that all developments strictly follow only one model- it is just a rough classification.

Physics for example has expanded tremendously from its early days and particularly since Maxwell. A solid state physicist of today may be totally unaware of what is happening in particle physics and may not even need to interact. But all these diverse fields are still part of physics. This is reflected in the education system and course and curricula. At the lowest level, that is at bachelors level, there is more or less uniform training in the “basics” of physics. There are very few –if any- bachelors program in solid state physics or statistical mechanics. But in the next stage that is at masters level the specialization’s are offered.

Compared to this, in many engineering fields- electrical engineering for example- when sizable expansions occur, new apparently “independent” fields appear which are generally considered to be separate disciplines. Electrical Engineering for example- when it started had no “electronics” component. Electronics was born inside it and when it became sufficiently “large”-it simply split out and is now considered a separate field. Similarly, computer science started as part of electronics and then became a discipline by itself. All these are now considered "independent" fields and separate bachelor level degrees are commonplace.

It is true that no field in its expansion rigidly follows one model, but a rough division is possible. Chemical engineering seems to emulate more of "science" model and all the recommendations for course and curriculum modification sited previously, favors this. While this is largely justified, splitting off some areas as " independent" subjects may be another way of coping with the recent explosive growth of chemical engineering. Some such splitting- particularly in areas which are "interdisciplinary" or "cross disciplinary" - have already occurred to some extent. Not only have Departments of Energy, or Environment have come up in many places, bachelors level programs have also been initiated. "Product" Engineering or "Molecular" Engineering may also come up. In the US, a PE examination in "Bioengineering Fields" is under active consideration. Such developments may end the monolithicity of Chemical Engineering , but may still be viable alternative and certainly will be explored.

Secondly the duration of training period also merits some consideration. The two cycle system in Europe may mean a 5 year training before joining the work force. A 5 year degree instead of the current 4 year should be given some serious consideration.

Globalization

Globalization does bring in a new dimension to Chemical Engineering profession - and certainly has strong implications on the training of chemical engineers. Globalization affects the chemical engineer in several ways- it makes them more mobile- being trained in one country and serving in another. They may also get part of the training at one place and rest at another. This requires a certain amount of uniformity in the training that is uniformity of courses and curriculum. And it also requires certain amount of uniformity in nomenclature- so that the course content is properly reflected in the name- and also some uniformity in the extent and depth of coverage.
Secondly it becomes necessary for the student to get acquainted with the laws, customs and practices of different countries. Of course the incumbent engineer does not need to learn the practices of every nation, but there should be some training that will make him able to learn and adapt to the situation.
Communication skill will be another aspect of training that is strongly affected by globalization.
Thirdly, the social and environmental impacts will require greater emphasis during training. Local and global effects of chemicals and chemical plants and social interaction/ effects will need to be carefully evaluated.

Thus the need for certain amount of uniformity is recognized by almost all schools all over the world, and some significant regional efforts like the Bologna convention- have been made, but there has not been any similar effort on global scale and lead in this matter need to be taken up by the well established professional societies.

While Globalization generally implies some sort of uniformity across the world, it may also harbor diversity- depending on the concentration of expertise at different locations/ institutes. Since the services will be available on a global basis, specialization may also flourish to much greater extent.

Harmony with environment and society

Possibly the most important lesson that Globalization teaches us is that we cannot live in isolation. Every individual, group, country or region is connected to every other in a very intricate manner and every action we take affects the rest of the world in some way.
It is now felt and accepted that "Chemical Engineering" and " chemical Industry" has to be in harmony with the rest of human existence and the human ecosystem. It cannot remain a separate compartmentalized field of activity disjointed and isolated from rest of human ecosystem.

A broader view of professional ethics would require the Chemical Engineer to be broadly responsible for all the consequences of his action, both individual and collective, and be responsive to the rest of the society and the entire ecosystem.

Globalization, making information flow very fast and effective, has also made us aware of the great diversity of view points and interpretations that exist in the world. Many of these world views may even be directly contradictory, yet each have its place in the tapestry of human domain. Learning to accept the existence of different world views is now necessary and the ability to understand and appreciate the "other view point" is desirable.

Ethics courses- many of which are in existence- and are mainly catered to by non-engineering Departments, may not truly project the ethical issues and conflicts a chemical engineer has to face in the context of operation of a plant or organization dealing with chemicals. But survival of the world now demands that we match our "wants" with our "needs". . While this has to be decided by the entire world society, we have to realize that "entire society" does include "chemical engineers", "chemicals" and "chemical plants" as well. So the Chemical Engineer has to take part, and use all the information and apply all the knowledge he/she has. But where or how does it fit in the context of "Chemical Engineering Education".

Teaching the concept of harmony and imparting a motivation to achieve it certainly cannot be classified as “technical part” of the training. But in order to practice it, a host of technical skills and knowledge becomes necessary. The chemical engineer needs to take a critical look at various processes and phenomena that does come under his field of knowledge and make this knowledge and analysis available to global scientific community . Thus he has to take a critical look at the chemical industry, and also chemical processes occurring in the environment, feasibility’s of products, processes and their by-effects. It is this aspect which requires training and hence becomes relevant in the present context- that is “Chemical Engineering Education”. .

Thus at the base level certain technical training becomes necessary or at least desirable. The engineer should know the effects - both long term and short term- of the products and the process plant on the human ecosystem. Long term effects need life cycle studies of the products, all possible effluents from the plant, effects of raw material procurement and problems like transport losses, accidents. That is the engineer must have a holistic view even at the conceptual design stage. The engineer must be trained to think naturally of costs to include these effects as well .

Thus it requires a change in attitude and also knowledge and capability for computing costs of all these factors. Normally courses on environment, pollution or waste treatment do not include this attitude or training. But these should be included at some stage of the training, and the methodology should be made an integral part of design course.

It must be realized that life cycle studies or associating costs with such effects are not the easiest of things to do. So possibly the best one can do at present is to inculcate the attitude- incorporating it as an integral part of curriculum. Quantification of such items require application of basic chemical engineering and chemical and biochemical principles- namely reactions, kinetics of reactions, heat and mass transfer, flows and mixing. So courses in heat transfer, mass transfer, modeling etc. should contain sufficient examples of applications of these basic principles to problems from these fields with as much real data as possible.

Evaluation of cost of product including the cost to the society, environment and ecosystem is also a difficult task and requires training. Economics and management courses should therefore contain discussions and methodologies for such evaluation- at least the basic concepts and methodologies. Apart from economics, such cost evaluation would involve considerable amount of statistics and associated mathematics- and elementary concepts need to be introduced in mathematics and statistics courses.

An integrated curriculum is required to enable the student to have a holistic view and be able to see the interconnections between the different courses and fields- and instead of seeing each part as a separate entity, he should see a "continuous whole"- and single field. And this field should blend "seamlessly" with "life", "reality" and human ecosystem.

Two other aspects also seem important. Firstly, there should be some awareness about " alternate materials" and "processes". This may be introduced as an elective course- and this course should at least include qualitative ideas about alternate materials and processes.

The second aspect is communication. This is already recognized and well stressed and included as part of curriculum in many programs. But in most of such courses, the emphasis is for communication with peers that is people in engineering, administration and management or at most with “labor” or “non technical personnel” serving chemical plants. But the skill to communicate with a non-peer- that is an ordinary person, who is not a part of "chemical industry community" or related to it, and has no or little knowledge about these, is also important. The engineer should be able to communicate with such persons, understand his concern and appraise him of the technicalities, in a way that he "understands" and finds correct answers to his queries. Thus the engineer also needs to have some competence in "popularizing science and technology"- so that he is able to communicate the facts in an undistorted manner to the uninitiated. And in doing so- this is where ethics do come in- he must be strictly honest, impartial and unbiased.

Some Suggestions

Needs for courses which deal with multiscale behaviour, process enhancement, analysis of chemical processes , product design with desired end properties, linking science with engineering practice with focus on modelling skills, creativity and ability to approach and solve poorly defined problems are well recognized and are being implemented, but social responsibilities of the chemical engineer must also be integrated into these courses.

Many departments and programs of courses do include instructions on environment, alternate technologies, nonconventional energy, - but usually in form of a separate courses. That may not be adequate- partly because most such courses are electives and there is no integration with the core chemical engineering courses. Such integration possibly requires that problems and student exercises for core courses be chosen from these fields. It also needs some changes in the simulation, modeling, design and project engineering courses. While most the basics or fundamental principles or methods may remain the same, the scope or the application field of these courses need to be enlarged.

At least one important new field need to be introduced- that is the methodology of valuation or ability to attach numbers to “fuzzy” items about which only “qualitative” knowledge is available.

In conclusion globalization does have direct and indirect effect on how the professionals should be trained. The increasing liability and the wider arena of activity requires apart from training in adaptability, ability to design and produce products meeting the exact requirements in quality, quantity and variety to satisfy the society.
In addition, there has to be a change of attitude- chemical engineering and chemical industries should not be looked upon as an independent self standing and separate institution but as an integral and harmonious part of the entire world society and human ecosystem.

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