# Chemical Engineering Education, where to now? – A global view

David Wood, Department of Chemical and Biomolecular Engineering, University of Melbourne, Victoria 3010, Australia.

**Abstract**

Chemical engineering education as manifested in the undergraduate programs available worldwide is stuck in the VIth decade i.e. the 60s & 70s of the first century of the profession. At the Glasgow World Congress in 2005 there was much criticism of the education offered to budding chemical engineers.
The Bologna agreement provides a way forward for the EU signatories with a five year two cycle program offering a bachelor and master degree but it is flawed and not generally accepted by British chemical engineering schools.
Major curricula and structural change is possible in the USA if the opportunities offered by the MIT led Frontiers in Chemical Engineering project are accepted.
The University of Melbourne, alone in Australia and the region, has its very own version of the Bologna Model commencing in 2008.
Despite the opportunity for change the vast number of undergraduate programs offered outside of the EU and the USA are very much stuck in the 60s model which is not good for the global future of chemical engineering education. This is at a time of unprecedented demand for the new age chemical engineer with skills required for the nano and bio revolution led by advances in molecular chemistry and biology.
The Profession must address the problem or face being cast into insignificance with the new age scientists showing the way.

## 1. Introduction

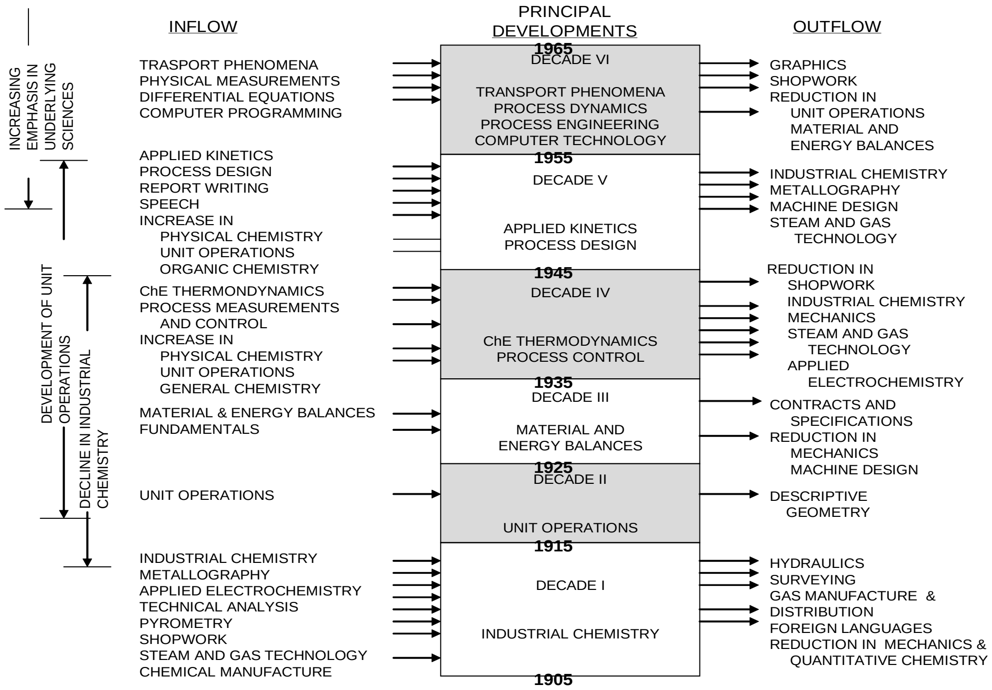
For some years there has been criticism of the current undergraduate chemical engineering programs. In spite of achieving the centenary birthday of chemical engineering in 2001, cries for change have been largely unheeded, certainly at the global level.
In the USA a major project was launched in 2002 by Professor Robert Armstrong who was then Head of chemical Engineering at MIT. The Frontiers project was very well presented in a Chemical Engineering Education publication in February 2006 (Armstrong 2006). Even if the need for change was broadly accepted in the USA there is at least a ten year time frame for implementation.
In Europe the Bologna Agreement (1999) signed by EU ministers of member countries provided the opportunity for radical change in chemical engineering education. It is unlikely that any change resulting from this will meet the requirements of the knowledge explosion in the Discipline.
Outside of the USA and Europe there are no signs of major change with one exception at the University of Melbourne in Australia but this new program is an imitation of the Bologna process with the same flaws.
This paper describes the changes that have been forecast and presents some data for chemical engineering education on a global basis showing the major impact of the presence of China which is almost certainly going to be a very large global provider of chemical engineering education and research. The paper offers some commentary on the Bologna Model and suggests that if we are going to keep up with the

knowledge explosion the way ahead is to follow the MIT led Frontiers Model where we have the opportunity to produce chemical engineering graduates ‘fit for the global purpose’.

## 2. Traditional Chemical Engineering Programs

Statements about traditional chemical engineering undergraduate programs have been plentiful over the past 10 years, particularly as the profession has considered progress over our first 100 years (Darton, 2003). As stated in the author’s paper presented to the InterAmerican Confederation of Chemical Engineering Conference in 2006 (Wood, 2006), a structured way of looking at the development of chemical engineering programs is to use the Hougen Diagram (Hougen, 1977) (Fig. 1) as presented by Armstong in 2006 (Armstrong, 2006).

**Figure 1**




An examination of undergraduate chemical engineering programs worldwide clearly demonstrates that whilst there have been some changes to the structure of the programs and also minor changes to the curricula, our universities remain in the 1960s and 1970s (Decade VI) for the major part of their chemical engineering programs. This statement is strongly supported by a number of leading international faculty members and was clearly made at the 7th World Congress of Chemical Engineering in Glasgow in 2005. It is time for change and if the chemical engineering fraternity fails to embrace change the opportunities for the future particularly in the biomolecular and nanotechnology fields will be passed to others.

## 3. The Challenge from Glasgow & criticisms of the current Education Programs.

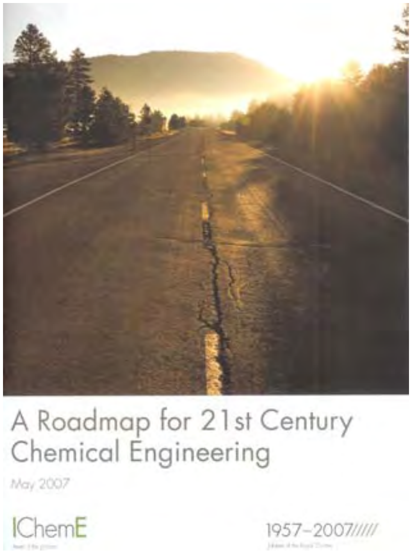
In considering the outcomes from the 7th World Congress of Chemical Engineering the IChem.E. produced four key challenges:

- Complex change is accelerating…where are the boundaries and limits of chemical engineering in the 21st Century – where do we play?

- Sustainable development – how do we move from ideas and debate to actual practice?
- Educating the next generation of chemical engineers – what should we teach and how?
- Supporting the profession – what must our international bodies do to help its members face the challenges that lie ahead?

The IChemE has addressed some of these challenges and in particular has produced "*A Roadmap for 21st Century Chemical Engineering*" (Fig. 2)

**Figure 2**




The Roadmap presents the challenges but does not provide a guide for educators in meeting them at the university undergraduate level, i.e. "Educating the next generation of chemical engineers – what should we teach and how?"
Ed Cussler in his keynote address to the Glasgow World Congress stated:

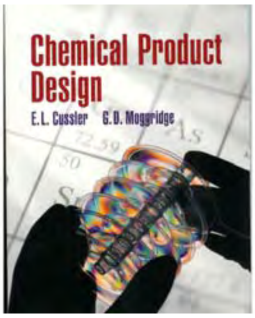
- *"Despite this fundamental change, (in Industry) the syllabus of chemical engineering courses has barely changed since 1975."*
- *"Is teaching in the profession at the crossroads?"*
- *"Half the chemical engineering departments in the USA have changed their names to Chemical and 'Bio-something' in recent years – the amazing thing is how many of them did NOT change the contents of their programs in any way while they were doing it."*

Of the numerous comments on chemical engineering education in recent years the following are restricted to the period 2001 to 2006.
In 2001 Cussler and Moggeridge published their book on Chemical Product Design. (Figure 3).

The introduction includes the following statement:-

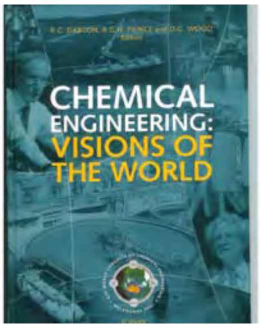
*"…in terms of responding to the changing requirements of Industry, we believe that chemical engineering education has done almost nothing". They added, "A glance at an old syllabus or textbook or a consultation with retiring academics reveals that the basic structure of chemical engineering curricula is essentially unchanged in the past 30 years…"*

**Figure 3( Cussler, 2001)**



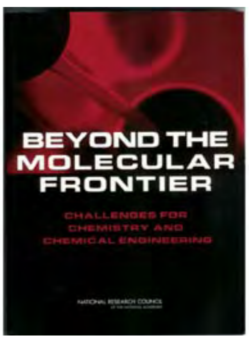

Also in 2001 at the 6th World Congress of Chemical Engineering in Melbourne, Bob Brown, then at MIT, in his Vision address asked *"How will chemical engineering education embrace molecular, synthetic and mechanistic aspects of engineering, particularly as we address the new biological industries?"* (Figure 4).

**Figure 4 (Darton, 2003)**




To fully understand the importance of Brown's comments reference to the excellent publication by the NSF, "Beyond the Molecular Frontier" (NRC, 2003) is recommended. (Figure 5).

**Figure 5**



In 2002 Bob Armstrong, then head of chemical engineering at MIT, commenced the "Frontiers in Chemical Engineering Education" project (Armstrong, 2003) which is ongoing. The project aims to reform the program content for chemical engineering courses in the USA and by 2006 over 50 departments had signed up. At the time, Armstrong stated that the discipline of chemical engineering has evolved dramatically over the past 40 years, yet the core curriculum has undergone only minor changes.
In 2005 at the National Australian Chemical Engineering Conference, CHEMECA 05, Paul Greenfield ( Deputy Vice Chancellor, University of Queensland) said "Undergraduate programs might have to be extended from 4 to 5 years" and he went on to suggest that a national Australian model for chemical engineering study should be developed. To have any commentary on undergraduate chemical engineering education from a senior chemical engineering faculty member and senior university manager is to be strongly commended although the concept of what was said should be challenged. It is interesting to note that over the years a number of statements have been made suggesting that engineering undergraduate programs should be of 5 years duration, presumably because of the 'knowledge explosion'. Surely chemical engineering educators are sufficiently innovative to design curricula that fit the 4-year professional undergraduate degree model.
In 2006 Armstrong published a paper which included an analysis of the development of the chemical engineering curriculum since 1900, the beginning of the Discipline. (Armstrong, 2006) He presents the work being undertaken on the Frontiers project and he states: *"…the curriculum for 1965 is very nearly the same as that used today. Why is this? It is possible that after 60 years of hard work on the curriculum the discipline arrived at a more or less timeless implementation. But this seems hard to believe in the face of all of the change that has taken place over the past 40 years outside of the curriculum. On the other hand it is possible that we have simply not paid the attention we should to curriculum development over this period."* I strongly recommend that all delegates present at this EFCE conference read Armstrong's paper and assess the chemical engineering programs under their care using Armstrong's analysis.
Not all chemical engineering academics agree with Cussler and Armstrong. In 2002 the University of Melbourne hosted an Australian professor from a prestigious American university who stated that one of the strengths of his chemical engineering programs was that the structure and curricula had not changed for about 30 years! This attitude should be condemned by all faculty members.

### 4. Why are we stuck in the 60s and 70s with much of our program design?

Chemical engineering as a separate discipline commenced just over 100 years ago in Boston and Glasgow (Darton, 2003). Undergraduate programs were created in both the USA and the UK and also in many other countries where the lead was taken from the American and British systems. The developments in Europe have taken a somewhat different direction with chemical engineering programs being somewhat more scientifically based, particularly with a strong emphasis on chemistry. This is also true for the countries that have emerged from the previous Soviet Union. In the Asian region the vast majority of undergraduate programs follow either the US model or the British model. The majority of text books have been sourced from the USA and the UK. Hence if the comments of Cussler and Armstrong are correct it is likely that the lack of attention to the curricula in the USA and the UK has flowed on to the majority of chemical engineering programs elsewhere in the World. So why have universities in the USA ,the UK and hence elsewhere neglected significant curricula developments over the past 40 years?

In his 2006 paper Armstrong suggests that the prime focus on research by academic staff has led to neglect of the undergraduate curriculum. He states *"This same period (since 1960) has seen an enormous growth in federal research funding in universities, and this growth has reflected in the large number of doctoral research programs in chemical engineering around the country"* This is also the situation in the UK and in Australia and is no doubt also true for other countries. Armstrong continues, *"This research has created valuable intellectual growth in our community, but it consumes an enormous fraction of the time of our faculty members just to keep the research engine running, with grant proposals, contractors meetings, review panels, annual reports etc. The price has been neglect of the curricula content in chemical engineering and the content taught in our undergraduate programs."*

Indeed at the University of Melbourne in addition to the regular detailed staff appraisals, all faculty members have to maintain an on-line log of their self-performance set against prescribed research criteria! Many of the faculty professors attempt to minimise their teaching duties due to the pressure of research performance. Furthermore the author cannot remember an occasion over the past 20 years when any of the senior professors contributed to the program curricula and structure debate let alone initiated discussion in this important area. The research productivity of our university chemical engineering departments has been prolific and the many conferences and high quality chemical engineering journals inform the worldwide chemical engineering fraternity of the many advances produced from this work. This is not confined to the USA and the same may be said for many other countries where academic staff seeking promotion have necessarily focussed on research productivity. The world of chemical engineering education is probably waiting for a lead from the USA or the UK in the area of curriculum reform and possibly program structure.

## 5. Bologna Model

The Bologna Agreement was signed in 1999 and much work has been undertaken by interested parties since that time. The Bologna process for undergraduate education involves a two stage education system. The first cycle degree is of three years duration leading to a bachelor degree and the second cycle degree is a masters program of two years duration. This provides a five year total program to achieve professional engineering status. There is to be a common credit system using European Credit Transfer Units (ECTU) and there are 60 ECTU notionally allocated for each year. (180 ECTU for the 3 year first cycle degree). The 2 year second cycle degree has 120 of ECTU.

There have been many statements and publications describing the Bologna Process. Molzahn published an article in 2004 (Molzahn, 2004) suggesting that the Bologna Process offers new opportunities for chemical engineering education. Indeed the 2 stage process if adopted uniformly throughout Europe has great potential for providing a major degree of transferability of education throughout the region. In his paper Molzahn briefly refers to the Frontiers in Chemical Engineering Education project in the USA initiated by Armstrong, (Armstrong, 2003). This project has very different goals to the Bologna process other than to encourage many different universities to examine their current degree programs.

The EFCE issued a statement in September 2005 which provides an excellent description of the Bologna recommendations for chemical engineering degree programs. It describes the “outcome driven” process which accords well with a number of professional accreditation systems used in many countries and the EFCE has recommended a minimum content for curricula in each of the cycles. The statement is somewhat prescriptive in its chemical engineering ‘subject’ requirements to meet a minimum of 65 ECTU in the 3 year cycle degree. It is easy for a chemical engineering graduate of the 1960s and 1970s to recognise the program and to conclude that the Discipline has not really changed in almost 50 years. The suggested ‘Basic Product Engineering’ might confuse such a graduate but everything else is well described by the program specified in the Hougen diagram of Figure 1. The second cycle (masters years) subjects are less prescriptive although once again the 1960s graduate would think that the Chemical engineering project is a reference to the old favourite, the Design Project. The requirement that the second cycle should include 15 ECTU of science and maths is surprising given that modern chemical engineering builds on a solid foundation of science and maths that should be well completed in the early years of a program.

## 6. The Melbourne Model

The University of Melbourne is a research intensive university and widely considered to be the university of choice in Australia. In 2005 the University made a decision to significantly reduce its undergraduate student numbers and increase the number of graduate programs. It was decided to adopt a university wide three plus two degree structure similar to that specified under the Bologna model. The intent is to enable all degree programs to incorporate breadth in the curricula thereby developing a wider skill set meeting broad attributes for the Melbourne graduates. In earlier years the undergraduates had been selecting combined degree programs to achieve the breadth and in Engineering the most popular programs were the combined degrees with almost 75% of students opting for them. Interestingly nearly all overseas students (~30% of the total) selected single degrees for financial reasons.

The new Melbourne Model commences with student entry in 2008 and the three year cycle for chemical engineering students is a bachelor of science offered via the Science Faculty. It will include a broad selection of chemical engineering subjects as well as the necessary science and maths. Similar to the Bologna Model the Melbourne Model allows room for broadening subjects.

Graduates from the first cycle bachelor degrees will seek entry to the two year master cycle where the chemical engineering is a major including a compulsory design project major and a compulsory research project major. There will also be broadening subjects in the master program. Whilst the three year bachelor program is essentially funded in the same way that undergraduate degree programs are currently funded i.e.approximately two thirds from Government and one third by student fee, the master program will be a full fee course with scholarships and fee relief available. Students entering the three year cycle are not guaranteed a place in the subsequent two year master degree and those who gain entry are not guaranteed a scholarship or fee relief. Hence the student could be asked to pay a fee approaching US22,000 pa. Engineers Australia has already agreed to accredit the full five year program for professional engineering purposes but the 3 year bachelor award will not receive accreditation.

Interestingly the Engineering School has decided to continue with the present four year professional engineering degree in order to attract full fee paying overseas students. It is also likely to continue to attract many excellent Australian students who are not prepared to commit to the potential of high fees in order to complete the professional qualification.

## 7. Impact for Global Chemical Engineering Education.

Major changes to degree program content and/or structure in the USA, the UK and to a lesser extent the rest of the EU can have a significant impact on chemical engineering education in the rest of the World. The founding countries for chemical engineering education were the USA and the UK and very many other countries adopted curricula and text books from the USA and the UK. Many countries in Europe followed a different more scientific approach.

Is it important to consider countries outside of the EU, the USA and the UK? The professional institutions now belong to regional federations such as the EFCE and we now have the InterAmerican Confederation of Chemical Engineering (IACCE) and the Asian Pacific Confederation of Chemical Engineering (APCChE). There is no regional body representing the African countries, the Middle East and many Eastern European countries.

When looking at major changes such as the Bologna Model and the changes that might occur in the USA following Armstrong’s Frontier work, countries in other regions and even in the same region may follow suit. Certainly no country wants to be left with decade VI programs. It is therefore worth looking at the spread of chemical engineering education worldwide. It is very difficult to obtain accurate figures for the number of chemical engineering programs that exist throughout the World and hence more difficult to make an assessment of the number of graduates produced each year. Maybe this is not important, however, the profession is very much a global profession and chemical engineers work in vastly different regions than hitherto. Also the impact of new materials, bio/nano technology, molecular processes etc require new skills which have no national boundaries. Multinational employers enable graduates to work in many different countries and regions. We might ask what impact will the Bologna Model have on educational programs outside of the EU.

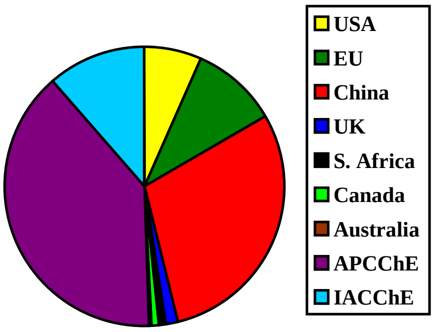
The author has gathered data from around the World via universities and professional institutions. Data from the AIChE Faculty data base has been used and in some areas best estimates have been made. Where estimates have been made the criterion has been the production of a professional chemical engineering graduate from a country where Washington Accord accreditation standards apply, at least in some universities. Figure 6 illustrates the data from Table 1 diagrammatically.

## Table 1

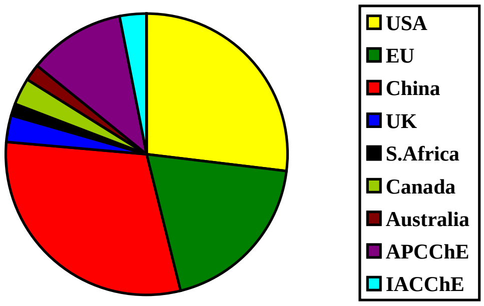
| Country | Population | Department | Graduates/yr |
|---|---|---|---|
| USA | 300 m | 155 | 5.000 |
| EU | 450 m | 110 | 4.000 |
| China | 1.305 m | 174 | 20.000 |
| UK | 60 m | 18 | 800 |
| S.Africa | 44 m | 7 | 160 |
| Canada | 33 m | 19 | 500 |
| Australia | 20 m | 10 | 450 |
| APCChE | 1.742 m | 64 | 4.000 |
| IACChE | 511 m | 18+ | 1.000 |
| Zone 1 | 1.113 m | ? | 557 |
| Zone 2 | 370 m | ? | 740 |
| Zone 3 | 699 m | 26+ | 2.000 |

## Figure 6

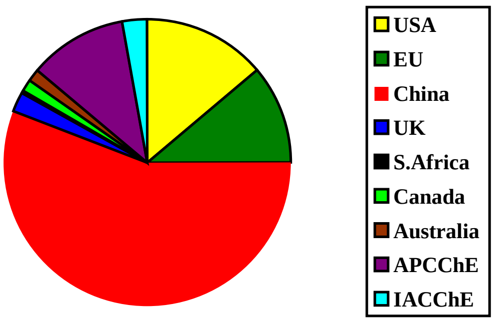
### Population




### Departments




### Graduates



The estimates for the USA, EU, China, UK, South Africa, Canada and Australia are based on reasonably well founded information supplied by reliable sources. The estimate for APCChE countries does not include China and Australia but does include India and Japan. These figures are gathered from the countries in the region and are reasonably reliable. The data for the IACChE region do not include the USA and Canada but the number of departments are those listed by the AIChE and it is likely that there are twice this number of departments. The figure for the number of graduates is an informed estimate. Zone 1 countries are those that are most likely to have a relatively low emphasis on chemical engineering education but for which no data are available. Such countries have relatively little industrial development and a low emphasis on tertiary education. Hence the figure for the number of graduates produced each year is an intelligent guess. Zone 2 countries are those predominantly influenced by the former Soviet Union where chemical engineering programs are very heavily weighted towards the chemical sciences and mechanical engineering. Again the figures presented for these countries are an intelligent guess. Zone 3 countries are those for which some data is available on an individual basis but the countries do not belong to one of the three confederations of chemical engineering. The figures presented for these countries are an informed estimate.

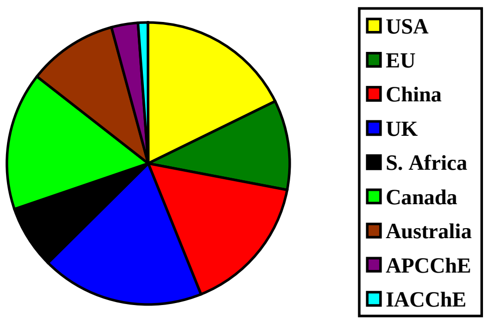
The figures for China stand out and few people outside of the APCChE zone are aware of the major growth in chemical engineering education that has occurred in China. We are all aware that for some time China has had a booming economy and its present GDP is approximately 9.5%, twice that in much of the rest of the developed World. In a relatively short period of time China will be the dominant country with respect to chemical engineering education in both teaching and research. Furthermore China has some outstanding universities on an international scale i.e. in terms of quality of staff, quality of students, facilities and research and productivity.

Table 2 and figure 7 present an estimate of the number of graduates produced each year per million of population and whilst China has a very large population it is also at the high end of the scale in terms of this parameter. The countries of the APCChE and IACChE regions not including China, the USA, Canada and Australia are well behind the rest of the World in terms of graduate chemical engineer production.

**Table 2**

| | Grads. per mill. |
|---|---|
| USA | 17 |
| EU | 10 |
| China | 15 |
| UK | 18 |
| S. Africa | 7 |
| Canada | 15 |
| Australia | 10 |
| APCChE | 3 |
| IACChE | ~1 |
| Zone 1 | ~0.5 |
| Zone 2 | ~2 |
| Zone 3 | ~0.5 |

**Figure 7**



**8.Commentary on the Bologna and the Melbourne Models**

There is great credit in developing a qualification that requires a learning outcome approach and indeed this is an appropriate monitoring function for professional accreditation institutions. The suggested EFCE 2 cycle program is somewhat curricula driven and this is quite contrary to the thinking of the accreditation agencies and those attempting to bring chemical engineering education into the 21$^{st}$ Century. If the recommendations of the EFCE for the two cycle program are adopted throughout Europe it will further encourage European undergraduate chemical engineering education to remain in the VI decade of Hougen's chart (Fig. 1). Certainly there will be some reform with recognition of the need to provide chemical engineering students in the first cycle with a broader base in separation processes etc. but who will be brave enough to completely revise the 180 ECTU into an entirely different structure from the prescription and yet still produce a chemical engineering education that is rigorous and befitting a 'new age' chemical engineer?

The University of Melbourne Model is even more prescriptive with the specification from 'those who must be obeyed' (Vice Chancellor and his deputies) that requires 25% of non engineering and science content in the first cycle!

A major criticism of both the Bologna and the Melbourne models is the requirement that five years are required to achieve professional accreditation status. The first cycle does not meet any of the accreditation requirements for professional engineering. Indeed Melbourne is retaining its traditional four year professionally accredited engineering degree so that it has programs that are attractive to overseas full fee paying students.

It is unclear what is happening in the UK. The UK MEng program is an undergraduate qualification that clearly meets the professional engineering standards (Washington Accord) in that country. The programs are of four years duration with the exception of those in Scotland where secondary schooling is different. Programs that are accredited by the IChemE are far from prescriptive and many have introduced great flexibility e.g. University of Manchester. Nevertheless there is much work needed to remove the programs from the VI decade.

A major problem for the two cycle Bologna undergraduate degree programs is the cost to the universities that participate. Much of the World is moving to a real cost recovery system from the students. In the UK high upfront fees are now charged which meet about one third of the cost. In Australia the situation is similar and there is no guarantee that students completing the first cycle of the Melbourne Model will receive scholarships, fee relief or interest friendly loans. Fortunately other high quality universities in Australia are not following the Melbourne Model. Tertiary education in much of Europe is at a low cost to the student. Surely this cannot continue with the very costly facilities and staff required in the modern university.

The commentary that if undergraduate chemical engineering programs do not follow a uniform structure this will disadvantage the graduates in obtaining employment in the international market is nonsense. Graduates from Australia and New Zealand have found employment in many countries over the years in spite of undertaking very different study programs to those offered in Europe or the USA or indeed China and Japan.

## 9. The Way Ahead

There is plenty of evidence that the message from Glasgow applies in all countries and chemical engineering education is in drastic need of reform. As can be readily seen, the developments in chemical engineering have progressed at an increasingly rapid rate over a number of years. This is particularly true in the biomolecular area and is well covered in "Beyond the Molecular Frontier" (NRC 2003). A number of commentators have pointed to weaknesses in our undergraduate chemical engineering programs which lead to our graduates being totally unprepared for the bio/nano era of the future. There is no doubt that there is an urgent need for curricula change and it is possible that there is also need for structural change in our degree programs. There is no evidence to support lengthening of the degree program as is required in the Bologna Model and the cost of such a move is prohibitive. Tinkering with the curricula and the Bologna approach being pursued by the University of Melbourne and possibly other universities is not the way ahead for Chemical Engineering education.

The suggestions proposed by Professor Bob Armstrong (Armstrong, 2006) provide the chemical engineering educators worldwide with an excellent model for curricula reform. The inflow in the Hougen diagram (Fig. 1) consists of new material and the outflow shows material which is withdrawn from the curricula to make way for the new content. In looking at the future there is no shortage of ideas for inflow but when it comes to deciding what should not be covered in the course many hurdles are presented. We have all faced this from our academic colleagues during curricula debates!

Armstrong suggests that the *"slate should be wiped clean"*! i.e. remove the total curricula content and start again taking account of the new developments in the discipline. His recommendation is that the new curricula for the next decade should be organised around the organising principles of molecular transformations, multi-scale analysis and systems analysis and synthesis. To quote Armstrong : *"This radically different curriculum would produce more versatile chemical engineers, who are needed to meet the challenges and opportunities of creating products and processes, manipulating complex systems, and managing technical operations in industries increasingly reliant on molecular understanding and manipulation."*

Armstrong is right and the World's chemical engineering educators should follow his example. Perhaps it is time for the EFCE and the other confederations to take the lead.

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