Integrating Chemical Process Design throughout the Curriculum

Can a framework process model serve to better integrate the design aspect of Chemical Engineering throughout the Curriculum?

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Abstract

Over the years we have observed that many Chemical Engineering and Engineering Chemistry students when they come into the fourth year one term Capstone Process Design course claim that most of the material is completely new to them. Making allowance for the expectations that students would claim this in any case, we believe that there are many advantages to trying to integrate preceding courses as much as possible with the fourth year design course.

What we are proposing is to develop a framework process model using a simulator such as PRO/II, UniSim, or ASPEN that would serve as a thread to link assignments in preceding courses such as heat and mass transfer. This model would then be used as the basis for the Capstone design exercise.

Although there are several potential advantages to this such as reducing duplication of effort and having a more cohesive design concept throughout the three years, there are bound to be teething problems.

One potential problem is a common understanding of design. There are many concepts as to what Chemical Process Design consists of, which reflects the background and experience of the instructors. What we hope to do is to keep in mind the definitions of Science, Engineering and Technology as stated at the Inaugural CDEN conference by Dr. Tom Brzustowski P.Eng., the president of NSERC. This talk clearly pointed out the difference between Research and Development as well as Design.

These are a continuum, Research, particularly speculative research is the least expensive and to a large degree the easiest of the three since there is not often the pressure to achieve a specific outcome. Development on the other hand which is primarily an engineering activity is considerably more expensive and usually has a fixed deliverable. Development is a team effort. There is a direct link between development and design since design cannot take place without the engineering development phase. The design and implementation of an artifact is the most expensive item by far and requires inputs from Economics, Environmental Health and Safety as well as knowledge of the market.

We are also aware of increasing demands on our engineering graduates from the two perspectives, the increasing competition on a global basis and the expanding core body of knowledge expectations.
Introduction

The Department of Chemical Engineering at Queen’s university supports two distinct programs, Chemical Engineering and Engineering Chemistry. In addition to the traditional process option in Chemical Engineering there is also a biochemical and biomedical option. Queen’s has a common first year. As required by the Canadian Engineering Accreditation Board, there is a Capstone Design course in the fall term of fourth year.

The CEAB requirements for a Capstone design course are as follows:

‘Engineering design integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems and processes to meet specific needs. It is a creative, iterative and often open-ended process subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may relate to economic, health, safety, environmental, social or other pertinent multidisciplinary factors.’

The engineering curriculum must culminate in a significant design experience which is based on the knowledge and skills acquired in earlier course work and which preferably gives students an exposure to the concepts of team work and project management.’

Rationale

As I am sure is the case at all Universities, the core body of knowledge considered to be fundamental to Chemical Engineering continues to expand. (1) This has many implications which have been the subject of debate for some time now, such as a mandatory fifth year, the basic professional degree being a Masters Degree and so on. It is not our purpose here to enter that debate, rather to discuss a proposal that might improve the efficiency of what we all do in the three years that students are (hopefully) in our program with respect to the design component.

For those of us who have been involved with the Capstone for quite a few years now, all of whom have had extensive industrial experience, it has become quite obvious that there appears to be a significant disconnect between the basic science and engineering science courses that have preceded the Capstone design course and the Capstone itself. This is as to be expected as the instructors in those courses have a different mandate and expectations than we necessarily have for the design course. We believe that if there is some way that we can better integrate the design course into the rest of the curriculum, it would have many benefits.

We are faced with the same mythology every year as a new lot of students show up for the “design course”, this year there will be in excess of 100 students. They claim that they have never heard of some basic fundamentals essential to survive the design course. This is certainly not unique to the design course. They often don’t see the application of the material presented in these courses and to some degree proceed to forget about the material once they have written the final exam in the course and received a pass mark. We are very strong believers in the concept that for most young adults, learning in the context of application is a most effective approach. This has been shown to result in better subject matter retention.

Another problem may be that for most of them this is the first real exposure of a problem based group exercise, where they would be assessed through the project rather than by mid-term and final
examinations. This transition from a sixteen year paradigm can be difficult for some.

From the other side of the equation we have to attempt to deliver an appropriate design exercise for our discipline. Chemical Engineering in this instance is somewhat different from our colleagues out there in Mechanical, Civil, and Electrical. We deal primarily with processes rather than “widgets”. The processes themselves are expanding exponentially. It is not that long ago that the potential employers of our graduates were mostly in the industrial chemical field, including hydrocarbon processing and the petrochemical field. We now find many of our graduates, at least those of whom remain in the profession, to be involved in a vast array of new fields, nanotechnology as one example. It is obvious that there is simply no way that we can address the needs of this vast array of potential processes so we rely on a process in the field of industrial chemicals, although we could very well look at any other area should we choose to do so. By doing this we also rely quite heavily on a commercial flow sheet simulator as a basis for the design exercise. This has some advantages and some disadvantages. The advantages are that the students are exposed to leading edge design technology, but we are limited in the level of “open ended design” that we can provide. In a perfect world we could have a qualified design specialist who would be perfectly familiar with these design simulators for each design group of say five students. For a class of one hundred students that would involve twenty such individuals, not very likely. It is simply not possible to find this many mentors who would be prepared to commit a great deal of time to the design course. In such an ideal situation each group could choose a process to their liking and with the mentorship of their advisor, pursue that specific design.

In the past when the Capstone design was presented over both terms rather than one, it was possible for the projects to be much more open ended in nature.

Hopefully some of the coordinated design projects in other courses can be more open-ended.

It is a major challenge to deliver the Capstone course in less than twelve weeks. Accordingly we select a specific process and spend a great deal of time “sanitizing” the model beforehand. We have no expectation that we can produce people with any real expertise in using these simulators, but from past experience we can discourage students quite quickly if we get into one of the many “alligator swamps” that are all too common with these simulators when the user is not all that proficient. Spending three days trying to get a column calculation to converge simply is not an effective learning experience.

So with a significant amount of trepidation we have developed a proposal that we hope may address some of the problems we have encountered. We have proposed that we develop a backbone process scheme that could be used through second and third years to link the course in those years to the Capstone course more effectively. This generic process would lead into the particular design process selected for the Capstone design course in fourth year.

A proposal for Integrating Chemical Process Design

A colleague of ours has been involved in developing a proposal to make use of large reserves of “brown coal” in Australia. This process is the classic pyrolysis, and water shift process which produces “Syngas” this being a mixture of Carbon Monoxide and Hydrogen. Syngas is the starting material for many chemicals and in our case Dimethyl ether (DME) from methanol. The process also produces power and would sequester the Carbon Dioxide surplus to the operation.

This process, a block flow diagram is given on figure 1 would be a suitable process. The concept that we would like to develop is that for example in a heat and material balance course one could select one of the units from this system to base the exercise around. Likewise with heat transfer and mass transfer, particular components of this design could be used. By doing this we would hope that the students would see this as something they would have to deal with in future, not simply some abstract exercise. Catalysis is another excellent example of where there could be an excellent linkage.

One other suggestion that has come out of this concept is the issue of economics. The ability to introduce the concept of “what would it cost” earlier in the curriculum is something we believe...
to be important. It has been suggested that a TA be expected to become proficient in handling the equipment costing routines that we have developed for the Capstone design course (these routines can also be used for Profitability Assessment should the need arise). This TA would not be assigned to any specific course but would be available either to provide tutorials or simply to assist students throughout the curriculum to carry out whatever capital and operating costs they might require.

This concept could be carried further. For example, a TA could be assigned the role of Unit Operations consultant. This would deal with situations such as the recent discovery that some of our academic colleagues did not know what a crystallizer looked like. This of course could fall into the broader field of separations.

The linkage to the design course is that for the upcoming Capstone Design course we have selected the process for manufacture of Dimethyl Ether from Methanol. DME is a compound that is used as a propellant and some have proposed using it as a fuel.

What we hope will result from this will be a greater understanding of how the material presented in previous courses all fits together in the Capstone design course. This understanding hopefully will extend to the TA’s as well as the course instructors. It is to a large extent an issue of teamwork, and sharing of expertise. We in the design field can not expect our colleagues in other fields to be conversant with design concepts than we ourselves have any appreciable in depth understanding of other specialties.

![Coal Gasification Framework](image)

**Figure 1**

**Path Forward**

Although we can see some real advantages here such as shifting some of the “teaching” load to the prior courses by linking examples to the backbone design, there are surely going to be problems. Problems will revolve around the issue of “design” itself. What is design? Amongst our colleagues there are several different concepts of design. We believe that design is part of the human experience. There are many aspects to “design.”
but in our case we are dealing with a subset known as engineering design. Dr. Tom Brzustowski P.Eng., the then president of NSERC at the inaugural CDEN conference presented the following two slides in his keynote speech.

These slides point to the problem. While design is the quintessential aspect of engineering, a “Research Intensive University” such as Queen’s puts its greatest emphasis on Basic Science and Engineering Science. Many faculty have limited professional design experience. This results in a problem in defining what in fact is “design” in the curriculum in the first place. In order for this integrated design experience to be effective this definition must be clarified. Following on from Tom Brzustowski’s definition these integrated projects should be as open ended as possible, and while relying on engineering science and economics, they should be predeterminately synthesis. The synthesis step is the creative aspect of design engineering. These projects should definitely fall into the Development field.

One issue that we must be aware of not only in this integrated concept but also in the Capstone design course is engineering vs. technology. While Process Economics, Environmental Health and Safety, as well as Compliance Issues are important aspects of engineering which must be considered in the design process they are not the primary aspect of design. Equipment selection and sizing, while essential for costing purposes, is also a function that falls to some large degree into the field of technology.

One of the major issues is becoming increasingly important in engineering education in North America is the phenomena of a “Flat Earth”. With the current situation with respect to virtually unlimited ability to transmit information around the world via the Internet, we find it increasingly difficult to compete in the area of technology. A technologist in China or India for example with computer tools available generally anywhere in the world can accomplish many of the fundamental aspects of necessary technology just as quickly and to the same high standard as a North American engineer can achieve and at substantially less cost.

It is in the creative aspects of engineering such as process synthesis where we hope to remain competitive. Here again this situation is changing. Several recent articles (2,3) have pointed out that although the expense of offshoring to India is rising, China has recently recognized that in order to shift from a predominately manufacturing economy it will be necessary to foster more creativity and innovation. This is one of the areas where our graduates have been most competitive, and we must strive to maintain this.

Conclusions

There are few conclusions to draw from this concept since at this time it is very much a work in progress; however we would be very pleased to have any comments and suggestions.

Reminder: R&D are very different

Research
- long-term programs of exploration and discovery
- new done mostly in the public sector, with some exceptions
- mostly led by scientists
- design engineering is generally limited to experimental equipment
- consumes wealth
- risk is scientific
- mainly open international flows of information, some patents
- successful research always produces more research; it also produces very important and revolutionary innovations, but they are rare and unpredictable

Development
- short-term projects with specific goals, often in response to market feedback
- private sector activity
- mostly led by engineers
- design engineering is essential at many points in the process
- consumes wealth, generally much more expensive than research
- risk is financial
- information closely held and protected: trade secrets, many patents
- successful development projects lead to innovations and new wealth creation through sales of new goods or services

...and so are science, engineering, and technology

Science: the social system for generating knowledge that involves three sequential and interrelated activities: research conducted according to a prescribed method (the scientific method), processes for accepting (or not) the results of research as fact, and finally predictions based on facts

Engineering: the professional activity of creating artefacts and systems to meet people’s material needs, with design as the central creative process, scientific knowledge and economic considerations as its essential inputs, and public safety as its overriding responsibility

Technology: the set of procedures and tools that predictably and reproducibly produces a specified desired effect in the material world

The main form of creative intellectual activity in science is research; it is both research and design in engineering.

The context for creative intellectual activity in science is an experiment, and in engineering it is most often a project.

Dr. Tom Brzustowski P.Eng., NSERC past president
1: Core and Supplementary Bodies of Knowledge for Chemical Engineers

Council of Professional Engineers as part of the CEQB of Knowledge Development Pilot Project

2: Watch Out India

Article in the Economist May 6 to 12 2006

3. Innovation Trends in China

Bob Stembridge, Thompson Scientific May 2006