APPLICATION OF CDIO PRINCIPLES IN AN INTEGRATED PROCESS AND PRODUCT DESIGN COURSE

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ABSTRACT

All B.Eng. courses offered at the Technical University of Denmark now follow CDIO standards. Recently (Spring 2008) a new course – 28156 Process and Product Design - was introduced in the Department of Chemical and Biochemical Engineering. The course has typically about 30-40 students. An integrated course combining the two disciplines of Product Design and Process Design has several challenges, not least because the subjects do not necessarily have much in common except a similar-sounding name. However, such a course gives tremendous opportunities, since it enables a student to follow the supply chain from raw material to finished product – at a time when a shift of the employment of chemical engineers from traditional bulk chemical positions to companies producing advanced products is observed.

From a CDIO perspective, it provides an excellent opportunity for a comprehensive implementation of CDIO principles in a single course. Already the traditional chemical engineering “capstone” design course has for decades embodied many of the essential features of CDIO (for example the focus on group work, development of interpersonal skills, the open-ended nature of design problems).

Another aspect of CDIO that is implemented in the course is standard 3 – Integrated Curriculum - meaning that the course projects draw on competences provided in other subjects the students are taking in parallel with Process and Product Design. This in turn has the benefit of requiring increased, broader teacher competence and forces teachers in different disciplines to communicate - which ties in with Standard 9 – Enhancement of Faculty CDIO skills.

KEYWORDS

Process and Product Design, Teamwork, Integrated Curriculum, Integrated Learning Experience.

INTRODUCTION AND BACKGROUND

The Technical University of Denmark (DTU) educates engineers in two separate streams of education, one stream being the Bachelor of Engineering (B.Eng.) which is a 3½ year program that qualifies the student to go directly into industry [1]. DTU’s management decided to introduce CDIO as the engineering context for all its B.Eng. studies, and implementation started in 2008 with first year courses. In 2011 the process will be complete.

In the Department of Chemical and Biochemical Engineering, the 3½ years (7 semesters) are arranged such that the 5th semester is where the students undergo practical engineering training in a company, and the 7th semester is devoted to the final research project. Large design/build projects are undertaken in the 1st and 4th semester [1].

Process and Product Design is given in the 6th semester, sandwiched between practical training and the final project. It is a large (10 ECTS points) course and is given simultaneously with Process Control and Reaction Kinetics (each 5 ECTS points). These courses thus offer the last opportunity for instructional education before the students begin working (some students choose to continue their education with an M.Sc. in Engineering, which they may do after undertaking certain “bridging” courses). Furthermore, the course Process and Product Design is designated as the “project course” for the semester, which means that the final course evaluation is based mainly on project work which must also include elements from the courses Process Control and Reaction Kinetics.

Product design as a discipline has been promoted very strongly in the department recently, with the result that (in addition to Process and Product Design) three courses are offered:

28110 Chemical and biochemical product analysis (5 ECTS points)
28410 Design and test your own product ideas (5 ECTS points)
28310 Chemical and Biochemical Product Design (10 ECTS points)

This last course is offered to M.Sc. students and is quite intensive, at 10 ECTS points, where a typical one-semester course is 5 ECTS points. In addition two DTU faculty members (Kiil and Vigild) are co-authors of a recently published textbook on the subject [2]. This book is also used as a textbook for 28156 Process and Product Design.

Process design as a subject on its own is taught to M.Sc. students:

28350 Process Design: Principles and Methods (10 ECTS points)

Again, this 10 ECTS point course is quite intensive. Process design was previously offered alone as a 7.5 ECTS points course to B.Eng. students in the 4th semester. The decision was then made from the Spring semester 2008 to move it to the 6th semester and combine it with product design to create the 10 ECTS point course 28156 Process and Product Design. In terms of weighting, the course is about 60% process and 40% product design. Two teachers are used on the course, one for product and one for process. Presently, product design is given first.

Both teachers on the initial course had taught their respective discipline (product or process design) as a full semester course. This gave challenges, since it was not possible to give each component of the course as given before – both sections needed to be cut down substantially (yet judiciously) in order to give meaningful coverage of the topics in much less time. It also meant that finding the connection between the disciplines was going to be tricky. Table 1 lists some of the characteristic differences between the two disciplines.

Table 1
Characteristics and differences between product and process design

Product Design	Process Design
Students typically choose a product to design	Students are told what process to design
Open-ended problem – wide choice of product and design method	Well-defined problem, limited scope for deviation from a defined solution
Best carried out with an interdisciplinary approach	Based mostly on chemical engineering fundamentals

The essential difference between the two is that process design is a “typical” chemical engineering subject, based on the fundamental disciplines students have learned (or are taking simultaneously). Product design, on the other hand, is much more open-ended – for example students are usually allowed to choose their own product to design. This makes a relevant process design much more challenging to find, especially since in process design students are usually given a single (usually bulk) chemical for which they must design a process.

In subsequent sections we discuss the structure and content of the course as it is now, and then discuss what we have learnt in the three semesters that it has been offered – what went well, what went less well, how can we improve the course and (not least) what additional demands such a course places on the teachers involved.

STRUCTURE AND CONTENT OF THE COURSE

The course is run over 13 weeks. Since it is a 10 ECTS point course, 2 modules are assigned to the course per week. In practice this means that the course runs from 9 am to 5 pm every Wednesday, with an hour's lunch break. Teachers have freedom as to how they utilize this time, but it is usually divided between short lectures, in-class problem-solving sessions, group exercises and project work. Especially in the process design part, extensive use is made of the "Databar" – a classroom where the teacher and each student have a computer in front of them. Problems and projects which require use of software are carried out here. The students can be guided through an exercise since the teacher's actions are projected onto a screen. There have been 30-40 students in the course over the three semesters it has been offered.

The first 5 weeks are devoted to product design and the last 8 weeks to process design. Two group projects (P1 and P2, with 4-5 members per group) are performed in product design and three projects are performed for process design. In process design, the first and third projects (P3 and P5) are performed in groups of 4-5 and the second project (P4) is performed individually. Project P2 follows on from P1. Similarly project P4 follows on from P3 and P5 from P3 and P4. For example, in process design, the students have had to design a plant that produces 100 000 tons per year of cumene. In project P3 the overall process flowsheet is defined and the students identify that the key unit operations are a reactor, several heating and cooling units, and 2 distillation columns for separation of the various products and reactants. Based on this (approved) flowsheet the students divide the individual units among themselves and then do a detailed design of these units individually. Project P5 then brings the whole process together again and the students perform an economic analysis of the process in the groups.

Projects P1 and P2 account for 40% of the final grade, Projects P3-P5 account for 50% of the final grade and an individual oral examinations accounts for the remaining 10%.

Product design follows the text by Wesselingh et al. [2] and divides topics into various categories, each illustrated with an example – table 2 shows the major topics.

Table 2
Steps in product design with an illustrative example

Steps in product design	Illustrative example
Analyse the situation	The design of an improved detergent requires an analysis of the process of washing clothes
Find needs	The design of double-glazed windows for sloping roofs needs improvement – interviewing customers is an important step. It turns out that "fogging" due to condensation of water between the glass

	layers is a major problem which occurs after years of use.
Specify the product	Toothpaste requires quantitative specification in terms of aroma, viscosity (can it be squeezed out of the tube), yield stress (does it stay on the brush), price, storage temperature, abrasiveness, etc.
Create concepts	Marine organisms stick to large ships and cause an increase in fuel consumption due to increased drag. Considering the solution to this involves many alternatives – should we add a biocide? Or use a pipeline instead of a ship?
Select a concept	Considering the various options available to diabetes sufferers led to the Novopen™ – a pen-shaped injector with a fixed dose of insulin.
Formulate the product	The correct formulation of a powder coating for refrigerators gives the right balance between “flow” and “reaction”
Flowsheet the process	Scale-up and optimization of production of herbicide capsules is aided by a flowsheet where track can be kept of materials, energy inputs etc.

In the initial stages of the course, students were free to select (almost) any project they liked. This is very time-consuming and subsequently product ideas were proposed, and the number was limited to 33 (only!). The aim of the projects was to understand (and possibly improve on) how many everyday items worked. Examples include tissues, towels, batteries, paintbrushes, centrifuges, dishwashers, rainproof fabrics, dough-rollers. The emphasis on product design in our context is thus on the application of chemical engineering skills and disciplines (mass and heat transfer, chemical reaction, thermodynamics, surface chemistry). While this turned out to be a big challenge for the students, it fits in exactly with the aims of CDIO.

Process design follows the text by Duncan and Reimer [3]. The students are introduced to the design process by way of examples from very different types of processes. These include processes for the production of ammonia, the purification of heptane, production of electronics grade silicon, generation of electricity from fuel cells, desulfurization of natural gas, desalination of seawater, refrigeration. The emphasis is on the features common to these processes. Detailed design of certain common unit operations is covered (distillation columns, heat exchangers). Reactor design is covered in the course on reaction kinetics which runs concurrently. Economic and environmental aspects of process design are also covered.

For the projects, the students have (up until now) been given a specific bulk chemical (cumene) and told that they need to design a process to make 100 000 tons of it per year. There are three projects in process design – the first and third are solved in groups and the second individually. However each project depends on the one before it, so collaboration (or at least communication) is required even in the individual design. During the course extensive use is made of the commercial design program PRO/II [4].

EXPERIENCES, LESSONS LEARNED AND THE WAY AHEAD

The course has had a mixed reception so far. Below is a selection of things that went well or less well based on the course evaluations.

What students liked

The interactive way the course is taught;
The use of real-life software tools;
The teaching method of lectures broken with problem-solving sessions;
Working in groups;
Focus on project work;

What students liked less

Some students felt that the day became too long – especially in process design;
Some felt that the product design was too open-ended;
The connection between the two disciplines was lacking;
Applying chemical engineering tools to products from daily life was a challenge for many students.

In future, more emphasis will be placed on showing the connection between product and process design. Some suggestions for this are discussed below.

Connections between product and process design

Flowsheeting in product and process design

One of the latter stages in product design (as discussed above) is to outline a process for actually making your product (possibly on a scale larger than laboratory). This usually takes the form of a block diagram with each block representing a conceptual step which needs to be performed. This may or may not be an actual physical step (unit operation) in the process. Figure 1 illustrates a flowsheet for the production of polymer capsules containing a liquid herbicide [5].

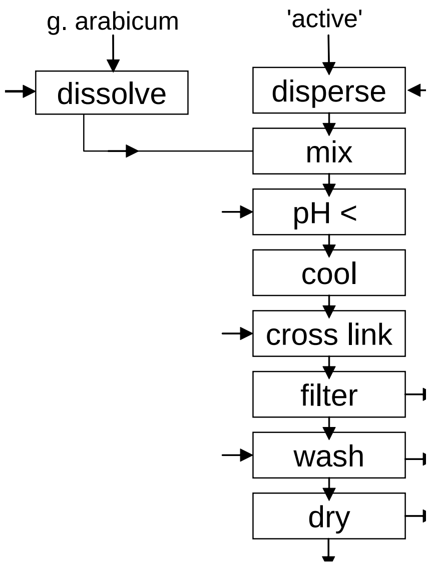

Figure 1. Flowsheet for production of polymer capsules containing a liquid herbicide

A process design flowsheet for the same product would contain actual unit operations for performing the desired transformations (a mixer for creating a dispersion of herbicide droplets in water, a reactor for pH adjustment, a heat exchanger for cooling, an extraction column for washing, a filter and a dryer, for example). Such a process flowsheet would like something like figure 2 [6].

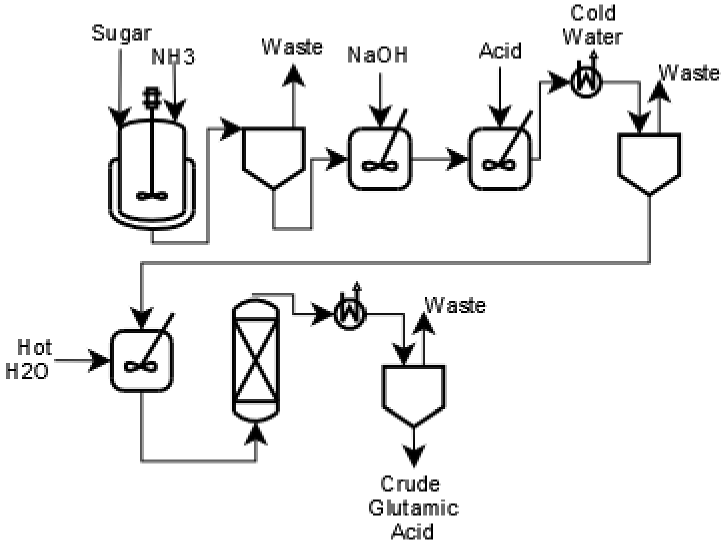

Figure 2. Process flowsheet for the production of glutamic acid.

The product is different here, but many of the unit operations are the same (reaction, mixing, cooling, reaction, decolorifying, cooling and crystallization. The key here is that each of these units represents actual physical process plant. It would be helpful in the course to make and emphasize the connection between the product and process flowsheets.

Relating the product to the process

Examples in Wesselingh et al. [2] and Ng et al. [7] discuss catalysts for the production of methanol and sulphuric acid. In catalysis, it is not only the chemical formula of the catalyst that plays a role, but also the shape of the catalyst. For example, a hollow cylinder has a higher surface to volume ratio than a solid sphere, while also reducing pressure drop on the reactor. Applying chemical engineering principles should enable the engineer to relate the overall conversion (and pressure drop) in a given reactor to catalyst size and shape. In designing a complete process for the manufacture of methanol, this will have a significant effect on all the other units in the plant – for example if the conversion is low in the reactor, more unreacted reactants will need to be separated and recycled, resulting in larger separation columns.

Another example of this connection could be the design of a pharmaceutical plant. The plant produces not only an active pharmaceutical ingredient at the right purity (process design) but also a finished product which must have the correct profile with respect to delivery (e.g. a slow-release capsule – product design).

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Biographical Information

Nicolas von Solms is an associate professor in the Department of Chemical and Biochemical Engineering, Technical University of Denmark. His background is in thermodynamics – modelling and measurement of phase equilibrium properties, mostly in complex mixtures (oil, polymers, gas hydrates, hydrogen-bonding fluids). He teaches Process and Product Design to final-year B.Eng. students.

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