Chemical Engineering
at Columbia University
in the City of New York

Product Design as an Undergraduate Capstone at Columbia University

Michael Hill
Rastislav Levicky[1]
Alan West

Department of Chemical Engineering
Columbia University
New York, NY 10027

[1]Current Address: Department of Chemical and Biological Engineering
Polytechnic University
Brooklyn, NY 11201

Chemical Engineering at Columbia University has a long & distinguished history, with the University chartered in 1754 and the Chemical Engineering Department founded in 1905. However, an analysis of employers, recent graduates, and established alumni has led to the strategic decision to shift the program focus for undergraduates away from traditional process engineering of commodity chemicals toward product and process engineering for specialty chemical products such as pharmaceuticals, fine chemicals, and consumer products.

While this shift has had implications for the entire undergraduate curriculum, it especially impacts the required senior design sequence. The fall semester course on Process Design focuses on processes for chemical products rather than commodity chemicals. These processes tend to be batch, so process simulation is taught with SuperPro rather than Aspen. The spring semester includes a capstone course on Product Design, which is the focus of this paper.

The Product Design course is comprised of a semester-long design project that requires students to generate product ideas and to perform thorough technical, economic, and risk analyses of their ideas. These tasks are supported by a series of lectures that deliver the necessary background.

Design projects are chosen for the breadth of chemical engineering skills required to do a proper design. Students are grouped in teams of 3 or 4, and assigned both a project and a faculty advisor to serve as a guide and coach fore the team. Teams meet with their faculty advisor once each week to orally present their progress, applying both elements learned from previous chemical engineering courses and the supplementary information presented in the weekly lectures. The advisor both critiques the team's progress and issues a team assignment for the following week. These design projects culminate in a formal written report and an oral presentation in MS PowerPoint, which is delivered to a wider audience, including some invited external experts.

Design projects typically adhere to the following generic schedule:

1. Course Introduction (1 week)

2. Customer Needs (1 week)
What are the general requirements for this product? What products are currently used? What is their composition, and why? How much do existing products cost to use? What are their limitations? What is the total market size?

3. Initial Technical Analysis (3 weeks)
What primary physical or chemical properties must this product have to be accepted in the marketplace? How can each key property be modeled as a function of composition?

4. Identification of Alternatives (2 weeks)
Using the property models, generate compositions that are likely to have all key properties.

5. Midterm Presentations (1 week)

6. Further Technical Analysis (2 weeks)
What secondary properties must this product have to be accepted in the marketplace? What generic ingredients may be used as additives to achieve the desired behavior? What target composition is recommended for further study?

7. Risk Analysis (1 week)
What are the key technical risks associated with this product design? How can these risks be managed?

8. Economic Analysis (2 weeks)
What are the expected variable and fixed costs? What ongoing market share is required for breakeven? What market share is expected, and why? What is the expected ongoing net profit? What investment expenses will be required, and how long will it take to recoup this investment, given the expected market share?

9. Final Oral Presentations (1 week)

There is no laboratory work associated to the design course, so design data must be obtained from literature or estimated by appropriate means rather than be obtained by direct laboratory measurement. This is good training, as industrial product designs often must be screened before chemical samples are obtained and hence before laboratory measurements can be made.

Past design projects have included an environmentally friendly aircraft deicing fluid, a device for removal of arsenic from drinking water, a dry cleaning fluid without chlorinated hydrocarbons, and a portable hemodialysis device. Typically these projects require students to demonstrate proficiency in thermodynamics, transport phenomena, and/or reaction kinetics, as well as extensive literature search skills.

Successful completion of a design project requires students to integrate elements of their previous chemical engineering coursework with the supplementary information presented in weekly lectures. This lecture material includes discussions of chemical product design principles, team working dynamics, project management principles, qualitative and quantitative project risk assessment and management, business economics, finance and accounting, and project portfolio selection and management.

These lectures also provide students with a set of practical tools that can help them throughout their careers, such as how to write a project brief based on stakeholder interviews, how to plan a product design project and predict the time and effort required for its completion, how to assess and manage the technical risks in a product design project, how to predict the ongoing sales volume required for financial breakeven, and how to resolve interpersonal problems in a non-functioning team. These skills are all practiced during the course in a chemical product design environment.

While some of the material taught in the supporting lectures might also be found in other engineering departments (e.g. industrial or mechanical engineering) or in courses taught in business schools, this course allows the material to be presented within a chemical engineering context, with immediate opportunity to apply the knowledge to a chemical product design project.

Our experience in teaching this course has taught us some valuable lessons. For example, recognizing that typical chemical engineering faculty members may not have the background and experience needed to teach this material well, it is advisable to make appropriate use of adjunct faculty. Alumni can also be a source of project ideas and can often serve as external experts to hear the final presentations.

Second, beware of the tendency to focus design projects on processes rather than products. It is tempting to allow students to do a superficial product design so as to allow them to focus their time on design of the process to make the product. While process design for chemical products can be within the scope of the course, this should be by a conscious decision rather than by default.

Third, be sure to emphasize key differences between the economics of commodities and chemical products. For example, commodity economics focus on the estimation of fixed capital costs, and the key decision criterion is about payback of investments during the financial transient. On the other hand, since chemical products are generally differentiated, there is far greater uncertainty in the obtainable market price of a new product. Hence product economics focus on estimating product unit costs, and the key decision criterion relates to the sales volume required to reach financial breakeven during the economic steady state.

Lastly, don't underestimate team dynamics. Prepare students to cope with interpersonal problems that they will not only encounter with their team members during the course, but will likely encounter throughout their careers.

Student feedback for the Product Design course has been overwhelming positive. Typical student comments were, "[The course] tied in both industry and academia to illustrate what chemical engineering truly entails." "Putting together all my years of training allowed me to remember why I chose engineering in the first place." "[This was] one of the best classes I have ever taken. Maybe my favorite one in the major." While receiving such comments is not the main criterion for success, it has been encouraging to see such enthusiastic student support.