Transforming Instruction to Chemical Product Design

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Undergraduate ChE design courses continue to focus on **process design**

Typical lectures and design projects assume the chemical product has been selected –

concentrate on creating processes to manufacture a product

i.e., How to make a product?

Not: What to make?

i.e., **product design**

- to satisfy customer needs

Process Design Courses

- follow engineering science courses that are process oriented

e.g., material and energy balances
open-system thermodynamics — Ideal and real gases; Simple phase equilibria
fluid mechanics — Newtonian fluids
heat and mass transfer — Shell and tube
separations — Equilibrium stages, simple mass transfer
unit operations
chemical reactor design — Simple reaction kinetics

While **product designs** involve

- selecting the best products to satisfy customer needs

  - are increasingly carried out by chemical companies (3M, G.E., P&G, Dow-DuPont, …)

  - often with **complex technology platforms** that characterize

    pastes and creams
    soft materials
    detergents
    paints
    drug delivery devices
    dehumidifiers
    and so on

To carry out **product and process designs**, often students need help in working with specific technology platforms

- can be facilitated when product and process design problems are coupled to the expertise of certain faculty members

  - ChE departments usually have faculty with different combinations of expertise profiles

    - to exploit these couplings, we seek to involve technology experts in creating product-design case studies to be circulated by CACHE

Next, consider approaches for blending in product design while emphasizing process design

I, Single Course

Teach process design
- using lectures with small design projects
- including a few product design concepts

II. Two Courses

1. Emphasizing process design

2. Emphasizing product design
   - often as an elective

Both involving design projects

III. Two Courses

1. Teach process design
   - using lectures without design projects
   - including some product design concepts

2. Design project course
   - process and product designs (occasionally involving both)

With the emergence of traditional ChE in developing countries; e.g., Saudia Arabia, China, South Korea, Vietnam,

companies in developed countries can no longer prosper by merely producing mature products

To attain a higher profit margin, they seek to produce innovative consumer products that enhance human comfort, health, and convenience. For these consumer products, product design is crucial.

The designer has to select the proper product ingredients and design the process to configure/process these ingredients in such a way that the final product provides the desired product attributes.

Pedagogically, product design strategies lead naturally to process design strategies.

To carry out product designs, students need examples of how to work with specific technology platforms.

A natural shift from traditional process design to new product design has been taking place for two decades.

Consider the hiring of **new faculty**. Few engage in traditional process engineering areas such as unit operations, reaction engineering, or process design and control. The majority are bio- and nano-oriented. These teacher-researchers are well-positioned to contribute to a product-process curriculum that aligns with their orientation.

Over past 5-years, Ka Ng has tried different product-design projects at HKUST. For each project, a team of 3-5 students is given a project statement, relevant literature, and guidelines for creating design reports:

Table 1. Products Used for Design Projects in Hong Kong

- Wine Aerator
- Faucet Water Filter
- Conductive Ink
- Vitamin C Tablets
- Hand Lotion
- Laundry Detergent
- Shampoo
- Toothpaste
- Mosquito Repellent Vaporizer
- Mosquito Repellent Mat
- IR Blocking Smart Window
- PM 2.5 Air Purifier
- Wound Dressing
- Magnetocaloric Fridge
- Refrigerator
- Air Conditioner with Green Refrigerants
- Building Air Conditioning System
- Phase Transition Type Heating Pad
- Energy Recovery Ventilator
- Conductive Paste for Printed Electronics
- Disposable Diaper
- Desiccant Dehumidifier
- Refrigerant Dehumidifier
- Respirator
- Portable Seawater Desalination System
- Wearables
- Powdered Milk
- Controlled Release Granule
- Membrane Bioreactor Biosensor

Because of the open-ended nature of these design problems, they do not have unique and complete solutions. Different student groups come up with very different products for the same problem statement.

While not a requirement, ideally the faculty adviser responsible for teaching product/process design teams up with another faculty member with **expertise in the fundamental sciences and applications** of the selected product.

Student learning is achieved in many ways. Each design team is expected to learn about the **underlying science and technology** for their product. This is achieved by **self-study** guided by the **domain-knowledge faculty adviser**

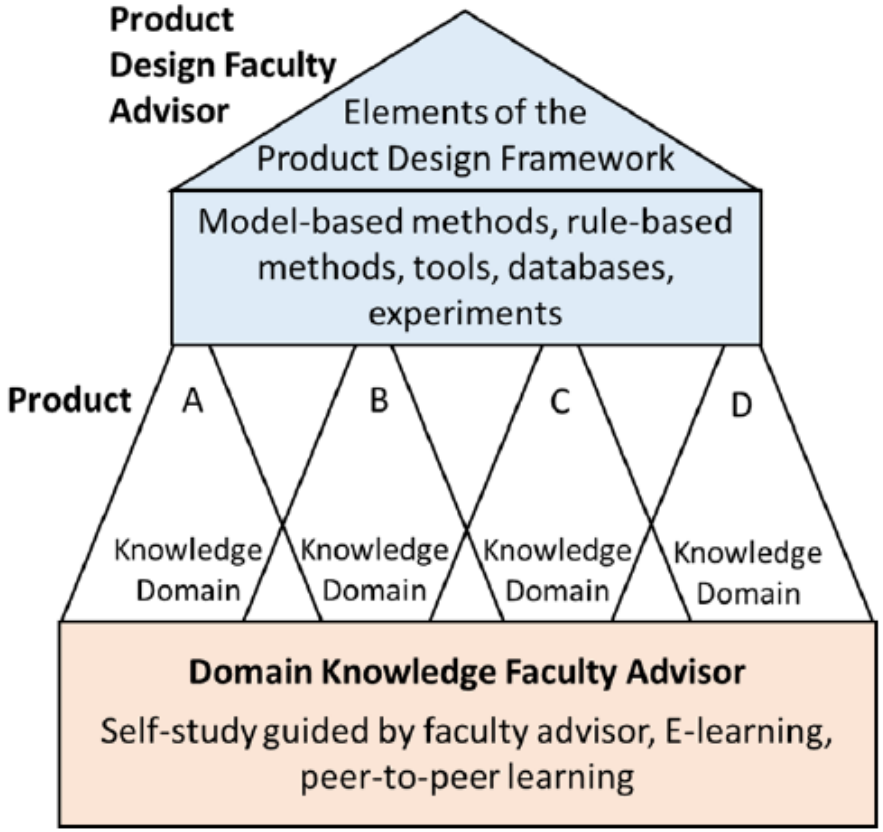


Figure 1. The students learn about how to perform product design and the domain knowledge underlying the product under consideration from the faculty adviser(s), E-learning, and so on. Each different product (of the four, A to D, shown here) is expected to involve a different knowledge domain although these domains are expected to overlap to some degree.

Experience Sharing

- S2015 CENG 6000F
  Advanced Product and Process Design
- S2016 CENG 6000I/4000D; S2017 CENG 6000I
  Advanced Chemical Product Design with Business Thinking
- S2018 CENG 4150
  Product and Process Design in Chemical and Biological Engineering
- Student feedback (verbatim):
  - It encourage creativity, not just focus on calculation
  - Nice and interesting project. Many real case examples are given to let us know more the existing innovative idea.
  - This is the only course that combines and apply the knowledge from all CENG courses. Extremely useful for FYP preparation and future work
  - It provides us a general picture for the product design, which all other CENG courses have never mentioned. The group project basically is a summary of what we have learnt and it facilities our understanding on the course content.
- S2019/S2020 Planning to phase it in as a required course

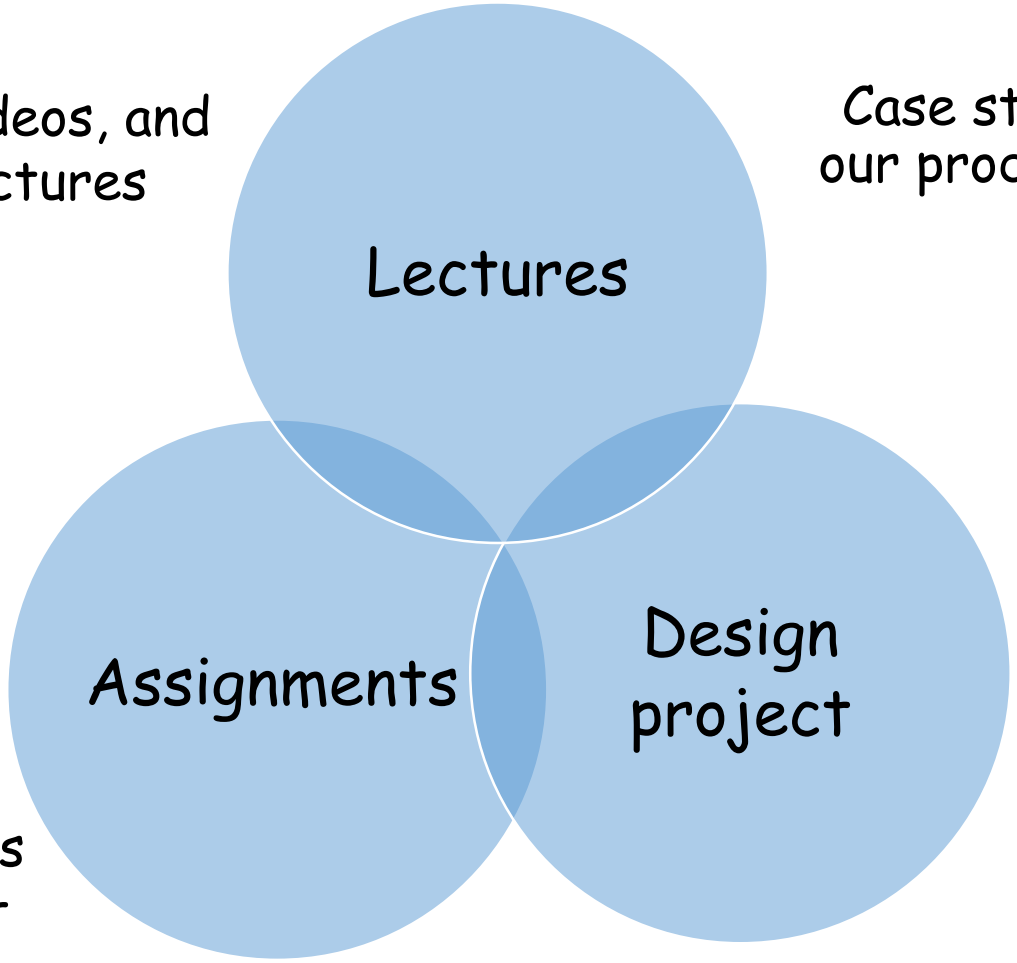
Course Objectives and Learning Outcomes

- Our goal is to introduce the concepts of and techniques for consumer-centered chemical product design. We will study the entire product life cycle from product conceptualization to product recycle.
- By the end of this course, students should be able to:
  - Appreciate the overall approach to product design from conceptualization to product launch.
  - Be familiar with some of the tools and methodologies used in product design and development.
  - Be able to design chemical devices and functional products with specified product performance by modeling the dominant physicochemical phenomena, and by accounting for the material properties and product structure.
  - Be able to decide whether a product project should be undertaken by considering the financial return and other non-financial issues.

Product Design: Course Structure

Lectures, videos, and flipped lectures

Case studies are used in our product design course



Exercises on unit operations and transport processes

Mastering the knowledge by designing a product

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Final Year Project

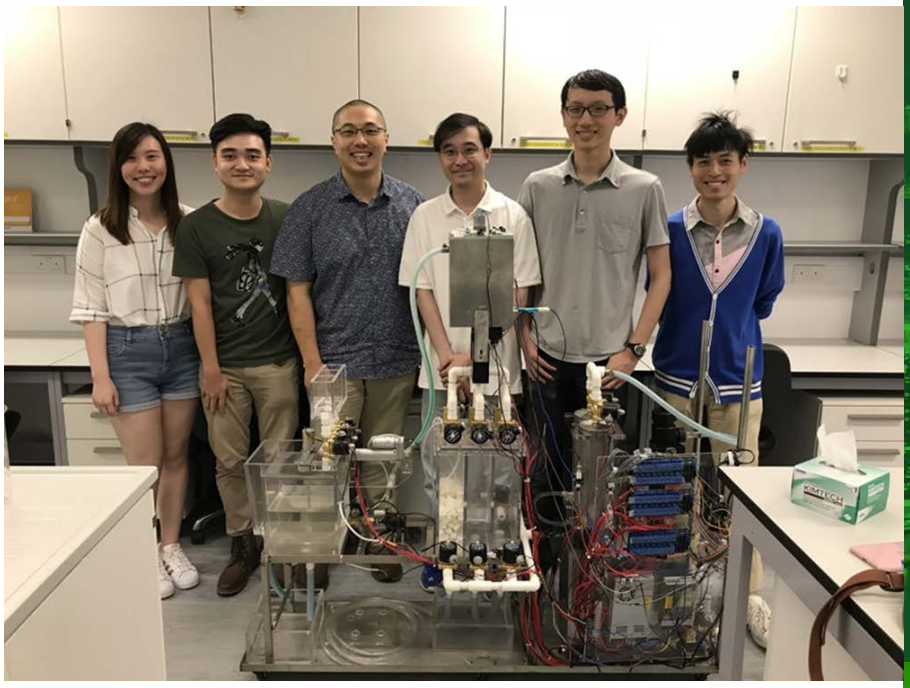
Design Project Final Report

- **Deliverables**
  - Describe the product and its desired functions.
  - Summarize the market study of the product; e.g., market size, major companies selling this and related products, competitive analysis, potential innovative products, and so on.
  - Identify the required product attributes to succeed in the marketplace.
  - Conceptualize the product; e.g., product microstructure, macrostructure, types of ingredients, and so on.
  - Determine the product specifications; e.g., the concentration of the ingredients, product performance, and so on.
  - Design the product manufacturing process; e.g., the flowsheet, equipment to be used, equipment operating conditions, material balances, and so on.
  - Provide a financial analysis accounting for the R&D cost, equipment cost, material cost, product life cycle, equipment salvage value, and so on.
- **The final report for course project (More is required for FYP)**
  - 20-min presentation (in the form of a **video**) + 5 min Q&A
  - A power point file that covers all the key deliverables listed above
  - An executive summary (3-4 pages) that summarizes the key ideas and results and an appendix (~ 5 pages) that provides further details to the executive summary.

Final Year Projects (10 of 15) for 2018-2019

Product	Faculty advisor
Developing a nutraceutical product in pill/tablet dosage form	Henry Lam, Nicholas Chan (Industry)
Hopping rates and impact on flavor profile, bitterness, tannins in a commercial brewery	Richard Lakerveld, I-Ming Hsing
Design an energy saving kettle with 3D printing	David Hui (w/CPEG)
Develop a food product with special properties/functions and design its manufacturing process	Marshal Liu
Design a needle core biopsy instrument with optical and photoacoustic feedback for improving surgical procedure	Terrence Wong
Development of non-flammable solid-state battery prototypes	Francesco Ciucci (w/ ME)
Design a reusable PM2.5 filtered face mask	Minhua Shao
Smart windows for solar control using nanoparticle-embedded polymeric interlayers	Ka Ming Ng
Fully conformable skin sensors for sports fatigue detection	Ping Gao
Development of a traditional Chinese medicine based standardized food thickener for elderly patients with post-stroke dysphagia	Henry Tong

FYP Team Wins President's Cup Gold Award in 2018



An FYP team consisting of two CBE and two CSE students won with their project "Autonomous Domestic Water Purification System with Mobile Application".

An NSF Project to Develop Innovative Chemical Products

Beginning with the HKUST product designs, more depth and breadth is needed.

This will be achieved with the help of faculty members having expertise in a research area related to a specific class of chemical products.

We submitted a proposal, and are creating an improved version, through CACHE to the NSF Education Division to develop these case studies. Although **rejected**, we have been encouraged to **resubmit this Fall**

These projects should educate students to be leaders and innovators in product design, which is being carried out increasingly by chemical companies worldwide.

Project Plan

We are inviting collaborators with relevant domain knowledge to help develop around **25 new case studies**. Some can be an **extension of the initial case studies** prepared by student design groups at HKUST and some can be **proposed by the collaborators**.

Our aim – produce a collection of case studies, a few of which will be aligned with the expertise profiles in each ChE department.

Tentatively, the project duration will be three years.

During the first 6-months of the project, the PIs will help refine the objectives of the proposed case studies.

After executing the project with one or two cohorts of students over ~2-years, the design project statements and solution alternatives will be demonstrated by the collaborator.

Project Plan (Cont'd)

~$10,000 will be provided to each of the US faculty participants to cover costs.

The case studies will be publicized in CACHE News and in AIChE Meeting sessions.

They will be distributed through CACHE, which has an extensive website (http://cache.org/) and has handled product orders in the past.

The revised proposal must place emphasis on **knowledge creation in engineering education**, and describe how the improved performance of students in product design will be **assessed**.

We welcome your ideas/participation. **Some might like to begin now without funding**.