

# Modular Teaching and Product Design Projects in Capstone Design

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**Abstract** - Some latest employment surveys show that chemical engineers are working in more and more diverse industries. For example, some of them design and manufacture specialty products, and need to understand property-structure relationships using chemistry, biology, and physics. Therefore, modular teaching with specialty product design projects would be useful, and should be integrated into the capstone design. Modular teaching can provide a means of responding to diverse and fast changing course contents and learning/teaching objectives. Product design projects come in various categories, such as separations, heat and mass transfer, kinetics, thermodynamics, or biotechnology, and incorporate DMAIC (Define, Measure, Analyze, Improve, Control) approach to achieve the goal of six sigma. Design teams are responsible from conception to manufacturing by considering green engineering aspects in one semester. This study presents the experience on modular teaching with specialty product design projects in the Department of Chemical Engineering at Virginia Tech. It discusses various product projects, learning and design objectives, guidelines, team effort, and preliminary assessments.

Keywords: Modular teaching, capstone design, product design projects, DMAIC

## MODULAR TEACHING

Chemical Engineering discipline has evolved to embrace biological engineering, and its graduates are working in more and more diverse industries. For example, they may work as product engineer to define products, understand property-structure relationships using chemistry, biology, and physics, as well as process engineer to design processes by using unit operations. Consequently, this emphasizes the constant need for revisions of teaching strategies and instructional materials in capstone design. One of the ways of achieving this goal may be modular teaching technique [Demirel, 3]. A module is a well-organized, high quality student text based on clear level, prerequisites, and learning objectives of a topic. Each module is dedicated to a topic, or a procedure. Modules mainly consist of three sections: title page, main text, and end materials (see Table 1); they can accommodate institutional and temporal variations, such as responding to diverse and fast changing learning objectives and the dynamics of accreditation in engineering education. They also follow new practices, the advancements in technology, and departmental curricular needs. Such demanding challenges may prevent conventional teaching materials, such as textbooks, that satisfy the learning objectives of capstone design for very long. However, the effectiveness of modular teaching technique still remains to be assessed properly [Brusic and LaPorte, 2].

The modules used in two semesters at Virginia Tech are: Introduction: Design Considerations, Separation Systems, Heat Transfer and Fluid Flow, Chemical Reaction Engineering, Thermodynamics in Design, Process Synthesis, Heuristics in Process Design, and Engineering Economics. Figure 1 shows the title page of module 2 on separation systems. Instructor can modify the learning objectives, contents and depth of modules from one semester to another. At the beginning of semester, students receive the modules and instructions of how to use them. Each module contains design practice problems and relevant references. The main text and the practice problems help students to transfer and synthesize knowledge across the previous courses, provide them with some examples of open-ended problems, and develop strategies in making engineering decisions under uncertainty.

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Table 1. Organization of a module

<b>Title Page</b>
Module identifier and name
Authors, revisers, and dates
Prerequisite competency list
Learning objectives
Modules covering same topic at different levels
<b>Main Text</b>
Introduction
Treatment
Summary
<b>End Material</b>
Problems
References

## Module 2

# Separation Systems

(Last update: Fall 2004)

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Objectives: you will learn design considerations for	Prerequisites
<ul style="list-style-type: none"> <li>• Useful separations</li> <li>• Distillation</li> <li>• Absorption and stripping</li> <li>• Adsorption</li> <li>• Extraction</li> <li>• Crystallization</li> <li>• Membrane separation</li> <li>• Filtration</li> <li>• Washing and leaching</li> <li>• Scale up of separation equipments</li> </ul>	Equilibrium-staged separations Mass and energy balances ChE thermodynamics Module 1

Figure 1. Title page of the module 2.

## PRODUCT DESIGN

Chemical engineers are involved in many innovative chemical and biological products. Some early products included tetra ethyl lead (TEL), DDT, cellophane, Freon, Bakelite, Kevlar, nylon, and calculator. Some new products are CDs, ink for ink-jet printer, color toner, insulin, zeolite, biomembrane, air purifier, composite membranes, advanced ceramics, and solar cell. These products have short and long term impact on the society and scientific and technological developments. They are usually high value products, may not need large capital investments, and manufactured in small quantities in batch processes. More over, specialty products need modifications and improvements constantly using the latest technology according to the needs of society. Specialty products engineering create a challenge for innovative thinking and manufacturing by considering the market dynamics and green engineering. Students would have an opportunity to test their abilities in designing and manufacturing useful products or modifying some existing ones under the time and budgetary constraints.

Due to impact of biological engineering and ABET criteria [ABET, 1], design projects in chemical engineering are becoming complex, and interdisciplinary. Some projects are motivated by industry concerns and prepare graduates for their work places [Hesket et al., 8; Shaeiwitz and Turton, 15]. Product engineering starts with the question: What and how to make a product? Engineer defines a product, relates the customer needs to property-structure relations of materials, and finally designs and manufactures. Product projects may be effective to teach how to research new knowledge, engineering analysis, and manufacturing a new product. Therefore, it is an opportunity to learn and practice engineering by manufacturing [Felder and Brent, 5]. Some design teams may also establish contacts with industrial companies, explore the current state of technology, and contemporary products.

### **DMAIC Procedure**

Six-sigma methodology aims at eliminating defects and improving product quality in design, manufacturing, and services. The DMAIC steps help applying the six-sigma approach to product design [Seider et al., 14]. The steps of DMAIC are:

Define (D) - Focused problem statements, project schedule in a Gantt chart, size, shape, and capacity.

Measure (M) - Literature search and prepare data base; process and material properties, toxicity & flammability, Material Safety Data Sheets (MSDS), and cost data.

Analyze (A) - Engineering analysis with assumptions, design of experiments.

Improve (I) - Improve product design and manufacturing steps.

Control (C) - Control your analysis with existing theory, quality control, evaluating results.

### **Design Teams**

Establishment of design teams is a key issue [Griffin et al., 7; Moor and Drake, 12]. Teams from previous classes, such as unit operations lab, may continue in design, since the members have previous teamwork experience. If a new team has to be formed, then members with different learning preferences might be considered. Index of learning styles [Felder and Soloman, 4] may be used to assess the learning preferences. Beside that, problem-solving styles such as adaptors and innovators [Hipple, 10] may also be considered in forming the teams. Beside other tasks, two members also serve as treasurer and safety engineer in each team. However, for students to function as team will occur through four development stages: forming, storming, norming, and performing [Stetson, 16].

### **Assigning Product Design Projects**

Table 2 shows some of the suggested product design projects in five categories within the Fall semester 2004. Teams choose a specific design project after deciding on a category. The department supplies \$250 for each product project. Teams must complete the design and manufacturing in about 12 weeks. Before a final report, each team prepares two progress reports. Table 3 shows the chosen product design projects by the eleven teams, and some related topics and concepts not learned in class.

### **Learning and Design Objectives**

The main objectives of the product design projects are:

- Learn in collaborative way [Gokhale, 6] and from experiments [Hesketh et al., 8; Raju, 13]
- Learn the current state of specialty chemicals & biological products technology
- Explore contemporary product and processes
- Prepare design problem statements
- Practice scientific and engineering analyses
- Manufacture a product
- Apply the Define –Measure –Analyze –Improve –Control (DMAIC) procedure in product design.
- Practice safety and green engineering [Hesketh et al., 9]
- Examine the viewpoints of customers and management
- Work with limited time and budget
- Work in teams and share responsibility
- Practice engineering ethics
- Practice engineering communication

**Table 2. Some specialty product design projects.**

Categories	Suggested Projects
Separation	<ul style="list-style-type: none"><li>• Composite membrane to separate mixtures</li><li>• Membrane for facilitated transport</li><li>• Drinking water purifier</li><li>• Waste water treatment-colloidal gas aphrons</li><li>• Air purifier</li><li>• Separation of oil from sand</li><li>• Soybean oil separation</li><li>• Practical adsorber</li><li>• Peanut oil separation by supercritical extraction</li></ul>
Heat and mass transfer	<ul style="list-style-type: none"><li>• Domestic heat and mass exchanger</li><li>• Heat storage units using phase changing materials</li><li>• External heat removing unit for laptops</li><li>• Solar desalinators</li><li>• Solar air heater</li></ul>
Kinetics	<ul style="list-style-type: none"><li>• Chem-e-car working with a fuel cell</li><li>• Popcorn machine</li><li>• Composite membrane-polymer membrane</li><li>• Smoke alarm</li><li>• Fenton's reagent for waste treatment</li><li>• Zero-valent metal for waste treatment</li><li>• Soap maker</li></ul>
Thermodynamics	<ul style="list-style-type: none"><li>• Ink for an ink jet printer</li><li>• Deicer</li><li>• An osmotic pump for drug delivery</li><li>• Ice cream maker</li><li>• Solar cell powered heater</li><li>• Thermoelectric device</li><li>• Crystallization device</li><li>• Electrolyzer</li></ul>
Biotechnology	<ul style="list-style-type: none"><li>• Protein separation- colloidal gas aphrons</li><li>• Soybean protein separation</li><li>• Germ killing surfaces</li><li>• Insect repelling wrist band</li></ul>

#### **General Rules and Guidelines for Design Teams**

- Product design projects are in five categories as shown in Table 2. Distributions of the projects among the teams are as follows: Three teams will pick up the projects from separation category, two teams from heat & mass transfer, two teams from kinetics, three teams from thermodynamics, and one team from biotechnology
- Design teams will prepare a memo to the instructor indicating the problem statement and a schedule
- Design team is responsible for the product design project from conception to manufacturing
- Teams will incorporate the DMAIC procedure in manufacturing
- Teams will consider the green engineering in design and manufacturing
- All the reports will consist of group evaluation form displayed in Module 1 (see Table 4), and records individual contributions towards design and manufacturing tasks

**Table 3. Product design projects.**

Teams	Chosen product design project	Some Related Topics not Learned in Class
1	Germicidal medical fabrics	Germ population measurements, medical practices
2	Solar electrolyzer	Solar panel, gas storage, corrosion
3	Ice cream maker	Hygienic operation, food preparation
4	Instant cooler	Refrigerant selection, corrosion
5	Desalination by reverse osmosis	Reverse osmosis
6	Chem-e-car with aluminum-air cell	Fuel cell, chemical power generation, Chem-e-car
7,8	Electrolysis fuel system and Chem-e-car	Fuel cell, chemical power generation and utilization
9	Adsorption of carbon monoxide	Adsorbent selection, regeneration of adsorbent
10	Cooling laptop computers	Fin manufacturing
11	Home fermentation and separation	Fermentation, filtration mediums

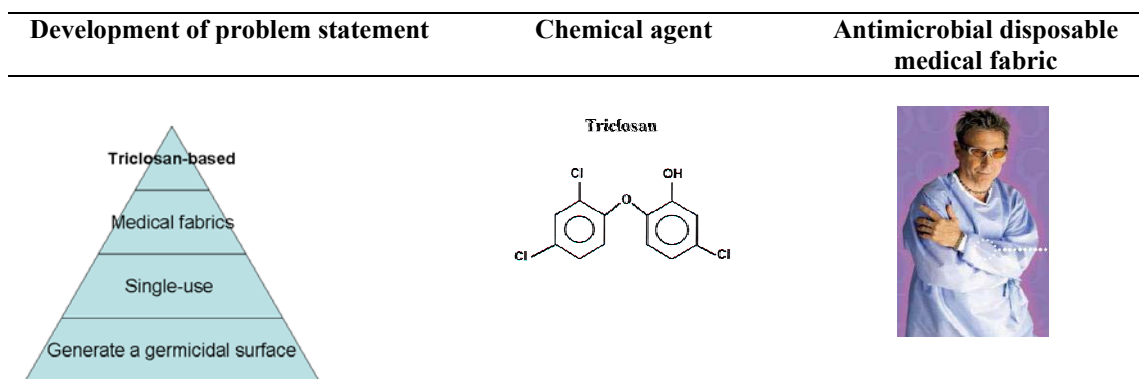
**Table 4. Team work evaluation form.**  
(1: not at all; 2: poorly; 3: adequately; 4: well; 5: extremely well)

		1	2	3	4	5
1	You worked with a detailed schedule for your design problem.					
2	You contributed ideas and information most of the time.					
3	You listened closely to each other most of the time.					
4	You completed your share of the load most of the time.					
5	Your performance within the group was more than satisfactory.					
6	You contributed mostly in literature review.					
7	You contributed mostly in model calculations.					
8	You contributed mostly in flowsheeting & simulation.					
9	You contributed mostly in economic analysis.					
10	You contributed mostly in environmental & safety issues.					
11						

### Some Examples of Product Design Projects

#### 1. Development of single-use germicidal medical fabrics using triclosan

Figure 2 shows the stages of the problem statement, structural formula of the agent and disposable medical cloth.



**Figure 2. Development of antimicrobial cloth using triclosan.**

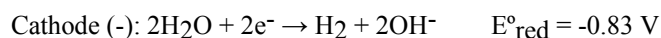
Triclosan properties are: (i) very soluble in organic solvents, (ii) non-specific biocide – kills all microbes, (iii) safe for use by humans, believed to interrupt many cellular processes, (iv) making resistance nearly impossible, waste water treatment techniques remove up to 96% of triclosan, (v) available as powder - reduces cost and increases versatility over proprietary agents.

The product manufacturing steps are: (a) dissolve 110 grams of crystalline triclosan in 1 L ethanol at room temperature, (b) cut 2" by 2" sample squares of PolyDrape® substrate, (c) immerse substrate sample in antimicrobial bath for 60 seconds, (d) remove substrate and press to remove solvent, (e) re-immerses substrate in bath for additional 60 seconds, (e) remove substrate and repeat pressing, (f) hang coated sample in fume hood to dry remaining solvent.

Three bacteria were selected for testing: Escherichia coli, Staphylococcus epidermis, Enterococcus faecalis: For the test, 500 µL of bacteria broth is used, it is allowed to soak into T-soy nutrient agar for 1 minute, then it contacted with cloth for 5 minutes. Later the cloth is removed and discarded, and the plate incubated at 30°C for 2 days.

## 2. Design of a small-scale electrolyzer for the production of hydrogen and oxygen gases

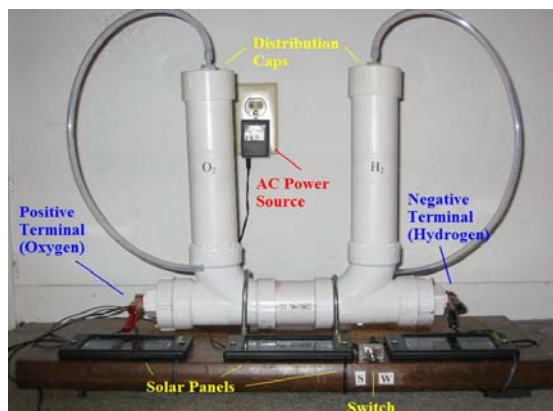
Team 2 constructed a solar powered electrolyzer for the production of hydrogen and oxygen gases (see Figure 3). Cost of electrolyzer is \$159.05. Design team has produced hydrogen gas by using three solar cells in electrolysis of water with the half reactions



Power requirement for producing of 0.5 L/hr hydrogen is 1081.76 mA. The power source is a set of solar panels with an AC/DC backup. Due to budget constraints, three solar panels are used. A total current of 450 mA from the solar panels produced 0.15 L/hr hydrogen with an efficiency of 75%. Electrodes are positioned 8.5 inches apart. The design team has emphasized that the ease of use should be considered as an important factor. Overall dimensions of the product are 16 x 28 x 9 inch cube. The electrolyte is potassium hydroxide, KOH, while the electrode material is stainless steel. The volume of hydrogen produced is calculated from

$$V = \frac{\left(8.314 \frac{\text{J}}{\text{mol K}}\right)(450 \text{ mA})(298 \text{ K})(3600 \text{ s})}{\left(96485 \frac{\text{C}}{\text{mol K}}\right)\left(1 \cdot 10^5 \frac{\text{J}}{\text{m}^3}\right)(2)} = 0.208 \frac{\text{L}}{\text{hr}}$$

This result shows a 75% efficiency in hydrogen production.



**Figure 3. Schematic of the electrolyzed powered by three solar panels.**

One of the critical factors for manufacturing is the current supplied to the electrolyzer. Advances in solar cell technology would give electrolyzer higher capacity.

### 3. Fuel cell powered chem-e car

The objectives are: (i) design and manufacture a fuel cell that runs on hydrogen and oxygen, and produces at least 20 mW and 0.74 V, and (ii) design and manufacture an electrolysis system to produce hydrogen and oxygen from water by utilizing solar panels to fuel the model car approximately 50 feet. The cost is approximately \$175.

Fuel cell is electrochemical device that changes the chemical energy directly to electrical energy and heat without combustion or moving parts. It is environmentally friendly, quiet, and efficient. It contains a proton-exchange or polymer electrolyte membrane where the electrochemical reaction takes place. Some of the important features are: lightweight, sturdy, heavy components located near axles, non-corrosive glue, excess amounts of tubing, cheap to manufacture, onboard storage of hydrogen and oxygen. Possible car innovations are: (i) taller water tank, (ii) glass beads on axle, (iii) detachable electrolysis unit, (iv) triangular supports on rear axle (see Figure 4)

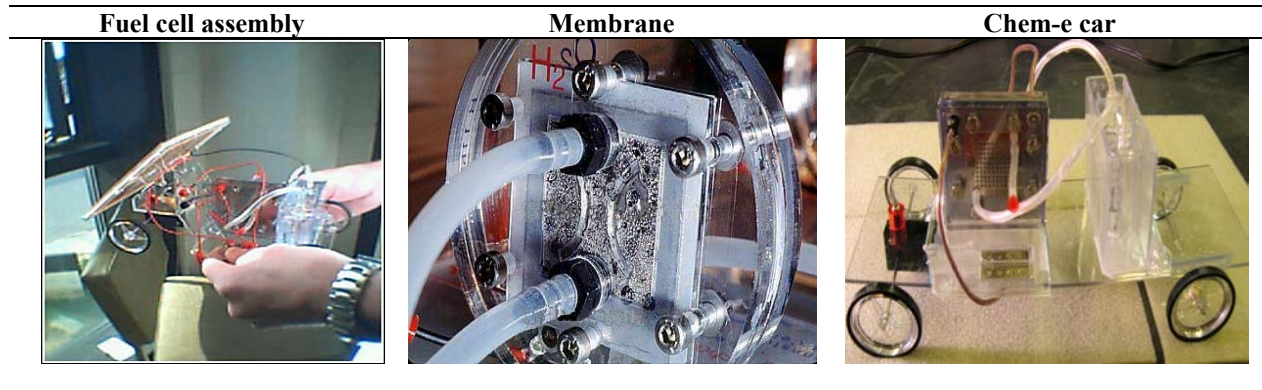


Figure 4. Chem- e car manufacturing.

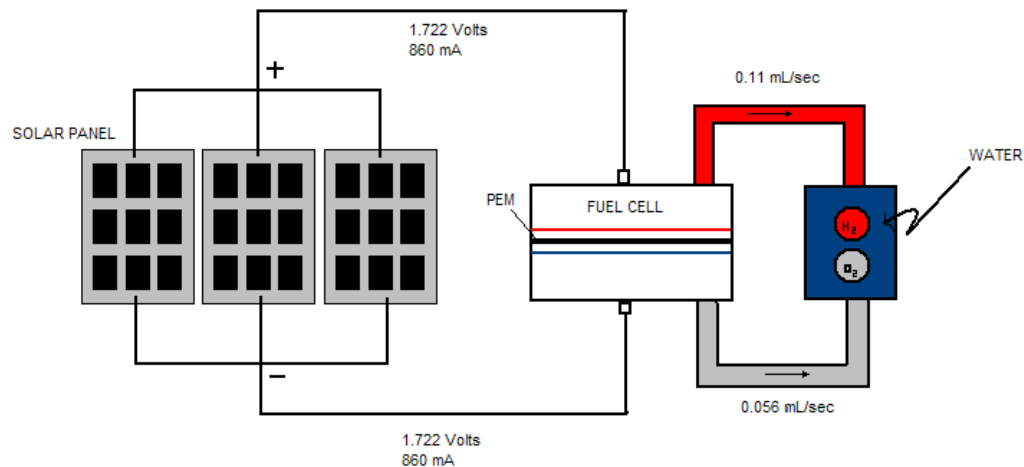


Figure 5. Schematics of solar panels and the fuel cell.

Some of the product manufacturing and development recommendations are: (i) power efficiency increases with fuel cells in series, (ii) work with a onboard fueling system; (iii) with more research it may be feasible to scale-up to a real automobile, (iv) one should increase pressure in the gas tanks, (v) car needs fine-tune axle alignment.

## Preliminary Assessment of the Product Design Projects (PDP)

Table 4 displays the preliminary questionnaire prepared by the author, and responses of 34 students in percentages.

- (1) Around 88% of the students think that PDP is teaching working in teams and dealing with unexpected circumstances in design and manufacturing
- (2) Around 90% of the students think that PDP teaches working with time and budget constraints
- (3) Around 60% of the students think that PDP teaches transforming knowledge across courses and incorporating engineering analysis in design
- (4) Around 75% of the students think that PDP teaches innovative thinking and communication skills
- (5) Around 75% of the students think that PDP teaches safety and environmental aspect of manufacturing
- (6) The majority of students think that PDP makes them more confident

**Table 4. Responses to a questionnaire on product design project (PDP)**  
(1: not at all; 2: poorly; 3: adequately; 4: well; 5: extremely well)

		1 %	2 %	3 %	4 %	5 %
1	PDP teaches working in team			12	26	62
2	PDP teaches working with time and budget constraints		6	3	32	59
3	PDP teaches working with DMAIC approach	6	35	41	15	3
4	PDP teaches how to deal with unexpected circumstances in design and manufacturing			12	56	32
5	PDP teaches market & literature search		6	41	38	15
6	PDP teaches transforming knowledge across courses and incorporating engineering analysis in design		8	30	41	21
7	PDP teaches manufacturing	3	18	26	41	12
8	PDP teaches communication skills		3	12	64	21
9	PDP teaches innovative thinking			21	38	41
10	PDP teaches safety and environmental aspect of manufacturing		18	47	32	3
11	PDP makes you more confident	3	3	26	56	12

## Some Student Comments

Some comments below may indicate what the students think of the objectives and outcomes of the product design projects:

*“ I learned how to work with other people in a much more effective way than I feel I could before this project. Working with other future engineers, technicians, professors, laborers, company representatives, experienced engineers-the list is endless.”*

*“ This project provided a fun and practical way to learn more about the ideas and principles involved in heat transfer and thermodynamics. Through construction and production, I learned the true value of heat transfer, insulation, and freezing point depression as well. This project also had the aspect of creating something from scratch to see the full design process. Taking the project from the research and development phase all the way to the construction and production phase gave me a real taste of what it takes to make an effective product.”*

## CONCLUSIONS

Modular teaching and specialty product design projects may enhance student's skill of transferring and synthesizing knowledge across courses, and learning new knowledge with hands-on practices [Demirel, 3]. Modular teaching can accommodate diverse and fast changing course contents and learning/teaching objectives. Specialty product design projects, on the other hand, may provide a real life experience on how to design and manufacture a product, and deal with time and budgetary constraints. Teams can learn by designing simple batch processes, applying engineering analysis, and manufacturing a product. Some of the benefits of such practices include collaborative learning by designing and manufacturing in team.



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