

EARLY PROCESS DESIGN EXPERIENCES FOR ENGINEERING STUDENTS

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Abstract--Typically traditional engineering schools emphasize design in the upper level engineering courses. Students experience open-ended engineering design in their senior capstone course. The College of Engineering at Rowan University has integrated engineering design at all levels of the curriculum. Students are exposed to the study of engineering design as early as their freshman year. In the first semester of the freshman year, students learn basic engineering skills (problem solving, teamwork fundamentals, engineering measurements) and are introduced to a variety of activities in each of the four disciplines at Rowan (Chemical, Civil and Environmental, Electrical and Computer, and Mechanical Engineering). This is followed in the second semester by intense study of engineering design through reverse engineering ("dissection") and competitive assessment (instrumentation, testing and side-by-side comparison of technical performance) of a consumer product. In this manner, students are introduced to design by studying the designs of practicing engineering designers.

This paper focuses on a multidisciplinary effort to introduce principles of chemical and environmental process design to freshmen through reverse engineering of consumer products. Three familiar consumer products--beer, bottled water and coffee are ideal for exposing students to fundamental physical/chemical treatment processes important for environmental and chemical engineers. By reverse engineering the processes by which these products are produced, students dissect operations such as mixing, grinding, heating, filtration, adsorption and ion exchange. Students are also exposed to fundamentals of fluid flow, mass and heat transfer and chemical reactions. The unique aspect of this entire course is the use of three common products to introduce the concepts of engineering process design and conventional treatment processes. Course assessment indicates that the students enjoy the experience of reversing a process and the semester long experience enhances their understanding of engineering design concepts. This early innovative early exposure to engineering design also impacts engineering student retention at Rowan University.

Index Terms: unit operations, chemical processes, freshman engineering, measurements,

INTRODUCTION

In recent years most engineering programs have introduced freshman engineering courses to attract and

retain students. These courses are typically structured to introduce the fundamentals of engineering design. Students traditionally work on a design project or study the design of practicing engineers. Reverse engineering on common household items is becoming a popular mechanism for introducing product design to engineering students [1,2,3,4,5]. Many schools have used various appliances or common household products such as toasters, hair dryers, toothbrushes, electric drills etc. to introduce reverse engineering to students [6,7,8]. *Reverse engineering is defined as the process that helps in developing sufficient information about a (product) form and function to allow replication with or without enhancement in original or current technologies, materials, and manufacturing processes* [2].

Freshman engineering students at Rowan University are introduced to the concepts of engineering design through a series of hands-on engineering experiments focussing on the principles of engineering measurements and reverse engineering. During the fall semester each engineering discipline introduces students to basic concepts of measurements through three-week modules [8,9]. These modules are focussed on the following topics:

- Manufacturing and Fabrication
- Structural Measurements
- Process and Flow Measurements
- Electrical Measurements

The above discipline specific exercises expose students to engineering design even though they lack the technical and analytical tools to solve realistic design problems. The first semester is followed by a semester long project focusing on reverse engineering. This course subtitled *Competitive Assessment Laboratory*, consists of a semester long project that introduces freshman engineering students to reverse engineering of a consumer appliance [4,5,6]. The major goal of this semester long experience is to expose students to engineering product design. The course is a 15-week, 3 credit course consisting of a 1.5-hour lecture and 3.0-hour hands-on laboratory. Lectures and laboratories are typically relevant to the assigned product. However some general topics such as life cycle analysis, design for the environment (DFE), ergonomics, engineering economics, intellectual property rights, professionalism and ethics are also included in the lectures to raise students' awareness about important aspects of engineering design.

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This paper focuses on three products that were introduced for the freshman reverse engineering module by the Chemical and Civil and Environmental Engineering Programs at Rowan University. These products were instrumental in exposing students to product design and process design. The product design aspects have been well documented [8,9,10]. This paper describes the early introduction of unit operations inherent to process design to a freshman class. Process design is an integral part of the chemical and environmental engineering curriculum. However most of the unit operations and process design courses are typically placed in the upper level (junior/senior) years. Products introduced to the freshman class included portable water filters, coffee makers and beer. Each product has a liquid end product for human consumption namely water, coffee and beer. Therefore reverse engineering of these products is intimately involved with chemical and environmental processing.

PORTABLE WATER FILTERS

Portable water filtration units are becoming popular for outdoor activities such as camping, hiking, mountain climbing, backpacking etc. A number of companies market these products (MSR, PUR, SWEETWATER, KATADYNE). A typical MSR water filtration unit with its components is shown in Figure 1.



Figure 1: Components of a MSR filter

These water filtration units typically have a number of conventional water treatment processes built-in to produce safe drinking water. The water filters have ceramic membranes, synthetic membranes, pleated synthetic filters, activated carbon, ion-exchange resins and iodinated components. Students have to identify and understand the basic principles of common water treatment processes such as filtration, ion-exchange, adsorption and disinfection. A hands-on laboratory is dedicated to enhance student learning and understanding of each treatment process. Each process introduces students to the need of a specific material for the treatment process. A

list of processes, materials and engineering design concepts learned are indicated in Table 1.

Table 1: Major Water Filtration Treatment Processes

Process	Engineering Material	Design Concepts
Filtration	Sand	Headloss
Adsorption	Activated Carbon	Isotherms, Breakthrough
Ion-Exchange	Resins	Selectivity, Resin Capacity
Disinfection	Chlorine, Iodine	Breakthrough Curve, Chlorine Dosage
Membrane Separation	Ceramic, Hollow Fiber, PES	Flux, Surface Area, Selectivity

Students also enhance their learning in three other areas:

- the importance of process variables such as flowrate, pressure and temperature on each process,
- the measurement of water quality variables to assess the performance of every process, and
- the characteristics of safe drinking water and environmental regulations dictating water treatment.

Water quality parameters that students use to assess the water filtration units include

- Turbidity
- Color
- Conductivity
- Organics
- Inorganics (such as nitrate)
- Presence and Absence of Bacteria

The water filters spark the students' attention irrespective of their engineering choices because of the inherent human interest in drinking water quality. Safe drinking water is of utmost importance to all engineering students as evidenced by the increase in use of bottled drinking water and Brita pitchers. Many students use water filtration units during camping and hiking expeditions. This accounts for their enthusiasm to learn about the engineering principles involved in the design of the water filters. The entire semester long module is cost effective. The cost of the filters vary from \$50 to \$120.

All other analytical equipment are already available in the Environmental Engineering Laboratory at Rowan University. The class also visits the New Jersey American Water Company's Delran Treatment Plant to observe surface water treatment.

A number of topics covered in general and discipline specific engineering courses are thus introduced to the students at the freshman level. The courses are presented in Table 2.

Table 2: Courses in Civil & Environmental Engineering

Engineering Materials
Organic Chemistry
Microbiology
Fluid Mechanics
Introduction to Environmental Engineering
Water Treatment and Design
Wastewater Treatment and Design
Advanced Unit Processes in Environmental Engineering

COFFEE MAKERS

Coffee makers are a common household product and coffee is a popular drink amongst students. The use of coffee makers to demonstrate common engineering processes is an innovative yet simple idea. Hesketh [11] and Hesketh and Slater [12] have demonstrated the use of this common household product to teach freshman common engineering processes. The unit demonstrates principles of material balances, fluid flow, heat transfer, mass transfer, thermodynamics, materials, process instrumentation and controls. Thus basic understanding of engineering design and reverse engineering can be demonstrated. A typical coffee maker with identified unit operations is presented in Figure 2.

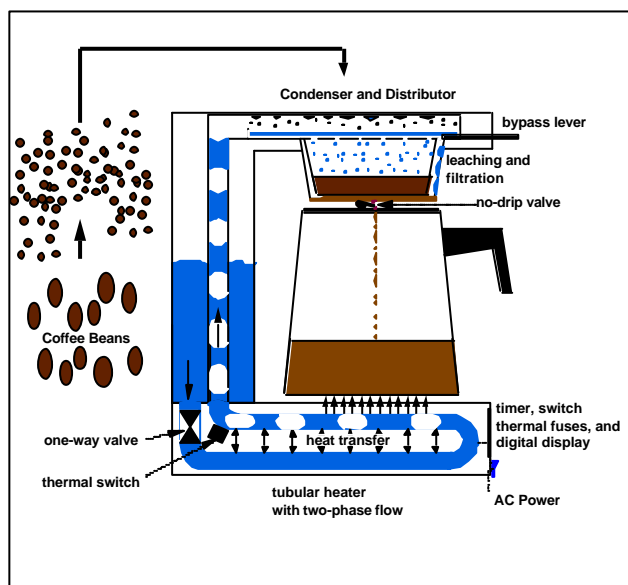


Figure 2: Unit Operations in a Coffee Maker

Some of the major unit operations in a coffee maker are outlined in Table 3.

Table 3: Major Chemical Processes in a Coffee Maker

Process	Raw Material	Design Concepts
Grinding	Coffee Beans	Particle Size
Leaching	Coffee Beans	Surface Area and Size Reduction
Filtration	Coffee Filters and Coffee Beans	Filter Porosity and Material
Solubilization	Coffee Beans	Effect of Temperature, Concentration Gradients

The process of leaching the organic compounds from the coffee beans uses principles from mass transfer, which is unique to chemical engineering. The process of grinding illustrates the impact of particle size on leaching and finally the final concentration of the product. The filter paper demonstrates material separation principles.

Parameters that students use to assess the various processes include:

- Color
- Coffee Concentration
- Taste
- Grinding time
- Particle Size
- Temperature

The coffee maker is thus a cost effective product to introduce students to basic chemical processes. The prices for coffee makers are as low as \$15 to expensive automated ones up to \$250. The coffee maker module is instrumental in introducing students to various chemical-processing concepts early in the freshman year. Courses impacted are listed in Table 4.

Table 4: Courses in Chemical Engineering

Fluid Mechanics
Thermodynamics
Organic Chemistry
Heat Transfer
Unit Operations
Mass Transfer
Engineering Materials

BEER

The third product that introduces students to chemical processing is commercial beer. Farrell et al. [13,14] have documented the use of the beer brewing process in enhancing student learning of product and process design. In reverse engineering an end product such as beer, students have to identify raw materials, chemical processing of the identified raw materials and parameters relevant to evaluate and assess the quality of the beer. The following table indicates the processes, raw materials and design concepts that are exposed to the students through this semester long reverse engineering exercise.

Table 5: Major Chemical Processes in Beer Brewing

Process	Raw Material	Design Concepts
Grinding/Mashing	Malted Barley	Particle Size
Fermentation	Wort, Hops, Yeast	Microbiology/Reaction Kinetics/Biochemistry
Sterilization /Pasteurization		Heat Transfer/Microbiology
Clarification		Remove particles, colloids, contaminants
Filtration		Separations
Carbonation	CO ₂	Vapor-Liquid equilibrium

Parameters that students use to assess the quality of beer include

- Color
- Foam
- Pressure
- PH
- Specific Gravity
- Alcohol Content
- Sugar Concentration

Beer brewing also involves numerous science and engineering principles such as fluid flow, heat transfer, material balances and biochemical reaction kinetics. The courses outlined in Table 4 build up on topics introduced to the freshman through the brewing process. This project is also cost effective, as it requires common analytical equipment for analyses of various parameters. Malt extract kits are readily available for making beer. Most of the vigorous fermentation occurs in the first 3 days with such kits. The class also visits the Iron Hill Brewery and

Restaurant (West Chester, PA.) for observing beer brewing in an industrial set-up.

SUMMARY

This paper demonstrates how reverse engineering of consumer products can be used to demonstrate not only engineering product design but also engineering processes to students as early as their freshman year. Products selected with some creativity can easily be used to introduce various aspects of unit operations in chemical and environmental engineering. Bottled drinking water, coffee and beer are popular household drinks. Therefore the initial unfamiliarity associated with unit processes is absent in using the above-mentioned products. All three modules are simple, cost effective yet innovative and interesting ways of introducing engineering processes inherent to chemical and environmental engineers. Each module can easily be adopted to include numerous multidisciplinary topics such as engineering business, marketing and economics, environmental and regulatory issues, manufacturing processes, electrical timing circuits, switches, remote sensing and data acquisition.

Students work in teams of 3 to 5 on an assigned product. The entire semester long project meets several educational objectives. Students are exposed to the creativity of engineering product and process design and basic scientific principles drawn from relevant freshman classes such as Physics, Chemistry, Mathematics and Biology. Students gain hands-on experience in analytical measurements and experimental design. Furthermore, students develop and strengthen their communication skills (written and oral) through frequent progress reports, laboratory reports, a final project report and oral presentations. Course evaluations indicate that all modules are effective in enhancing student learning and capturing students' attention. The most important impact of these innovative freshman modules is the impact on student retention at the College of Engineering. Student retention for male and female students for the graduating classes of 2000, 2001 and 2002 are similar and is presented in Figure 3.

CONCLUSIONS

Commercial beer, coffee, and water can be easily incorporated in a simple, cost effective innovative way to introduce concepts of reverse engineering and engineering product and process design. All three products are an excellent means of introducing basic chemical and environmental unit operations as early as the freshman years. The water filter and coffee maker projects can spark interest in engineering careers.

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