Chemical Engineering Principles in a Freshman Engineering Course using a Cogeneration Facility

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ABSTRACT

The primary goal of Rowan University's freshmen engineering course is to immerse students in multidisciplinary projects that teach engineering principles using the theme of engineering measurements in both laboratory and real-world settings. Currently, many freshman programs focus either on a design project or discipline specific experiments that may not be cohesively integrated. At Rowan, freshman engineers are introduced to industrial problems through a series of 4 modules and a interrelated-interactive lectures on problem solving, safety and ethics. In this paper a the process engineering module using the vehicle of a cogeneration plant is presented.

INTRODUCTION

The Rowan engineering faculty are taking a leadership role by using innovative methods of teaching and learning, as recommended by ASEE[1], to better prepare students for entry into a rapidly changing and highly competitive marketplace. Key program features include: (i) inter- and multi-disciplinary education created through collaborative laboratory and coursework; (ii) stressing teamwork as the necessary framework for solving complex problems; (iii) incorporation of state-of-the-art technologies throughout the curricula; (iv) and creation of continuous opportunities for technical communication. To best meet these objectives, the four engineering programs of Chemical, Civil, Electrical, and Mechanical Engineering have a common engineering clinic throughout their program of study. In addition to the engineering clinic, they share a common first year of courses. Our first class of entering freshmen consists of 101 students having an average SAT score of 1274 and graduating in the top 12% of their high school class.

The current Freshman Engineering Clinic sequence, which is taught in the Fall and Spring semesters, has laboratory components for all of the major disciplines. Some institutions have utilized traditional discipline-specific laboratory experiments at the freshman level (Perna,[2]), while others engage students in discipline specific freshmen engineering design projects (McConica[3]). One of the NSF coalitions, *ECSEL* has major efforts in freshman design, which have been widely reported (*e.g.*, Dally and Zang[4], Regan and Mindermann[5]). In our freshman engineering clinic we are using a series of 4 experimental modules to teach engineering principles.

The overall objectives of the Freshman clinic are to expose students to engineering measurements incorporating engineering fundamentals while helping them acquire strong communication skills. These objectives are detailed below:

Engineering Measurements: *Students will* understand and apply the concepts of accuracy, precision, resolution and linearity; calibrate devices; have a knowledge of the basics of data acquisition; analyze a problem and select appropriate measurement devices *for actual engineering processes*.

Engineering Communication: *Students will* produce plots using Excel to illustrate engineering principles; use PowerPoint for presentations; use word processing for reports *of actual engineering problems*. *Students will* develop the ability to work in multidisciplinary teams, have effective meetings, and utilize a problem solving strategy *on real engineering problems.*

Engineering Fundamentals: *Students will* convert units, examine equations for dimensional homogeneity; use engineering equations; apply basic concepts (e.g. hydrostatic pressure, Hooke's law, Ohm's law) *applied to actual engineering problems*.

Four measurement modules are employed in this freshman engineering clinic: manufacturing, structural, process and electrical engineering. Spatial measurements and measurement fundamentals are introduced to freshman engineering students as they fabricate a MAG style flashlight from an aluminum rod. Several structural measurements are shown to the students using a bridge module. Students first survey a bridge site, conduct strain measurements on a model bridge and simulate the bridge. The university cogeneration plant is used to demonstrate temperature, pressure, flow and concentration measurements. The students tour the cogeneration plant and obtain readings from the cogeneration unit. The students return to the computer laboratory and simulate two heat exchangers using their readings and perform hand calculations for homework. This is followed by two weeks of experiments using temperature, pressure and flowrate devices seen in the cogeneration plant. The final module has the students construct a temperature alarm circuit and investigate the use of C++ programming in measurements. Thus the clinic focuses on measurements in the field and also in traditional laboratory settings.

Process Measurements Module

This module simulates a "day in the life of an engineer." A problem is posed to students requiring them to visit the university cogeneration facility. At this site both traditional (gauges and thermometers) and data acquisition measurement systems are employed to monitor the steam and electricity generation process. This laboratory and homework session is followed by two more laboratory sessions in which students perform process measurements using equipment similar to that used in the cogeneration plant. The module lasts three weeks; with each week having a 1 hour and 3 hour session.

Preceding the cogeneration site visit students have had lecture and problem sessions on teamwork, safety, system of units and unit conversions, dimensional homogeneity and significant figures. On the day of the site visit, the students are given a brief introduction to the cogeneration process and are shown photographs of equipment that they will need to identify on the site visit. Next they have directed activities in the plant followed by a computer simulation exercise. The experience is continued with a homework problem using the cogen plant readings.

The instruction objectives for this module are presented to the student as:

Instructional Objectives

At the completion of this module on the cogeneration facility you should be able to do the following:

1. Convert units of simple dimensions.
2. Convert units of a variable such as flowrate.
3. Given a gauge pressure and an appropriate equation, calculate the temperature of saturated steam.
4. Examine an equation for dimensional homogeneity.
5. Obtain measurements of temperature, pressure and mass flowrate and perform an energy balance on the heat exchangers in the cogeneration system.
6. Create a simple heat exchanger network using the chemical process simulator HYSYS.
7. Identify from a photograph the following: orifice plate, pressure transducer, thermometer, and pressure gauge.
8. Describe the process of cogeneration to a high school student.

Cogeneration Plant Introduction

Rowan University uses steam for both heating and cooling of its buildings. An additional benefit to the process is the generation of electricity. It is explained to the students that the process unit in which both electricity is generated and steam is produced is called a cogeneration unit. It is obvious to most students how a building is heated with steam using radiators, but it is not obvious how to cool a building with steam! Professors are probably aware that steam is used with absorption refrigeration[6,7,8] and I am very pleased to see that the best treatise on this subject is in Perry's chemical engineering handbook![9]

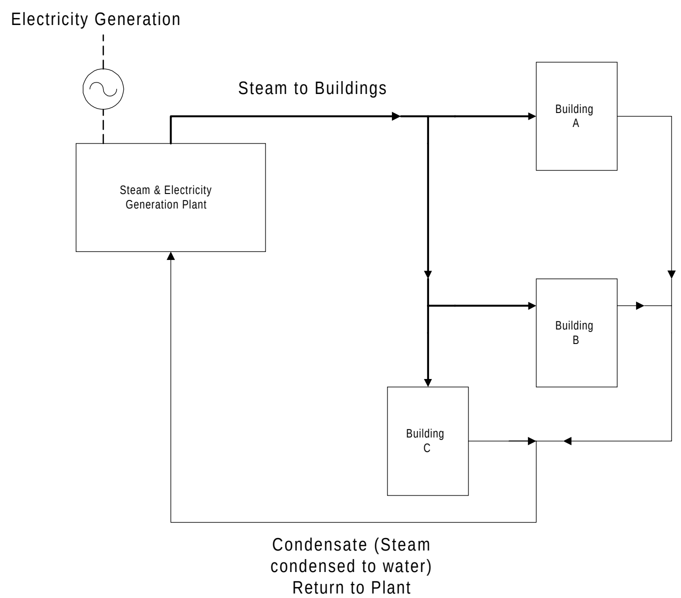


Figure 1 Overall Schematic of Rowan University Steam & Electricity Generation

The overall flow diagram for the use of steam at the university is shown in Figure 1. In the Rowan University Steam Plant, steam is produced by the three boilers and a cogeneration unit. Steam flows through underground pipelines to each of the university buildings; through radiator units or the refrigeration absorption units (air cooling) and then is returned as condensate to the steam plant. In our new engineering building these units are located on the 4th floor and I am attempting to modify this laboratory to use this floor for future engineering classes!

An advantage of using this steam plant is that both traditional (gauges and thermometers) and data acquisition measurement systems are employed. There are many *traditional* gauges in this plant for measuring temperature, pressure and liquid height. At the other end of the spectrum is

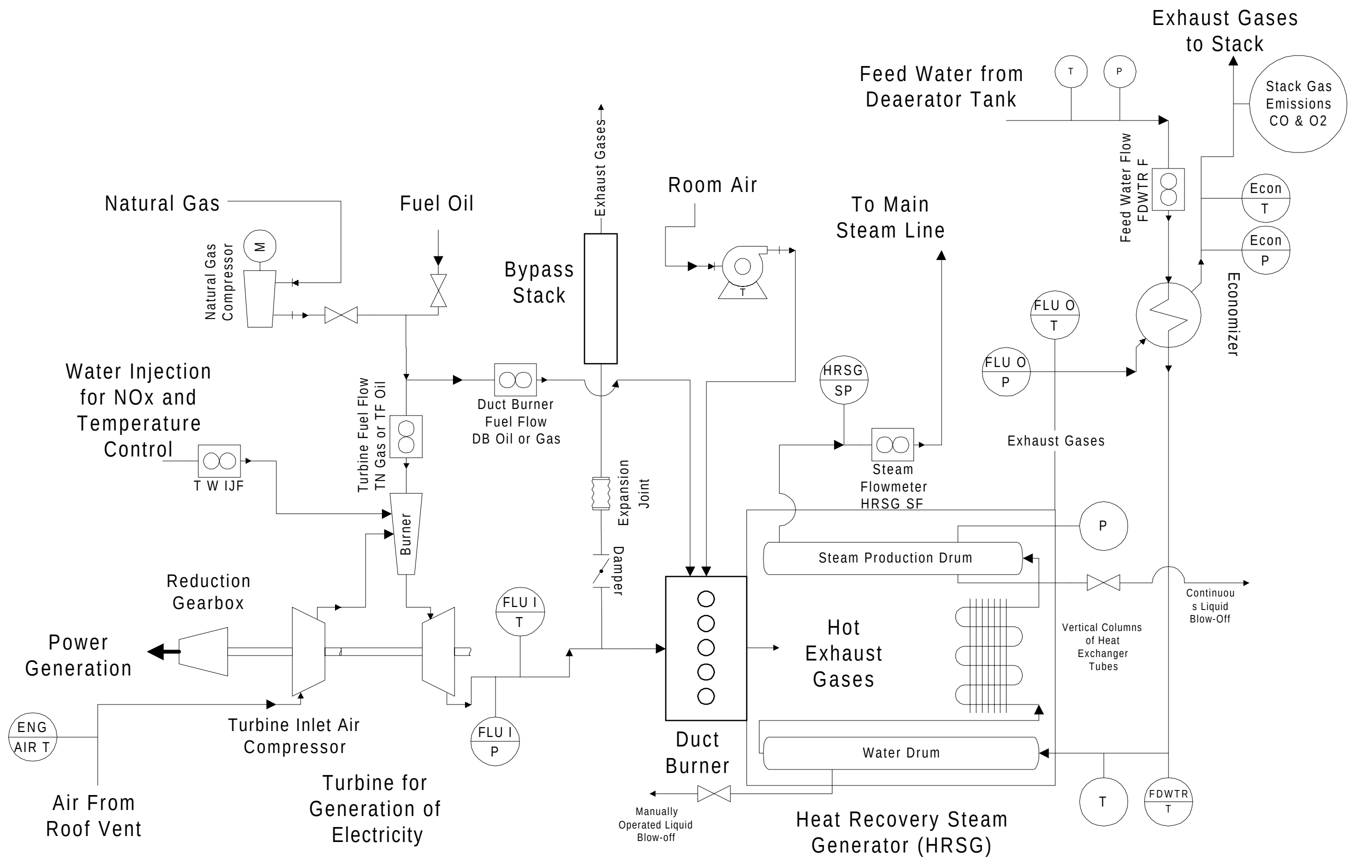


Figure 2 Rowan Cogeneration Plant Fabricated by Energy Recovery International

the advanced data acquisition system records 65 channels of information including vibrations, power, voltage, amperage, temperature, pressure, gas, solid, liquid concentrations, and flowrates. Students are able to see the advantages of using both mechanical gauges and pressure transducers. Also given throughout this module is the cost of various types of measurement equipment.

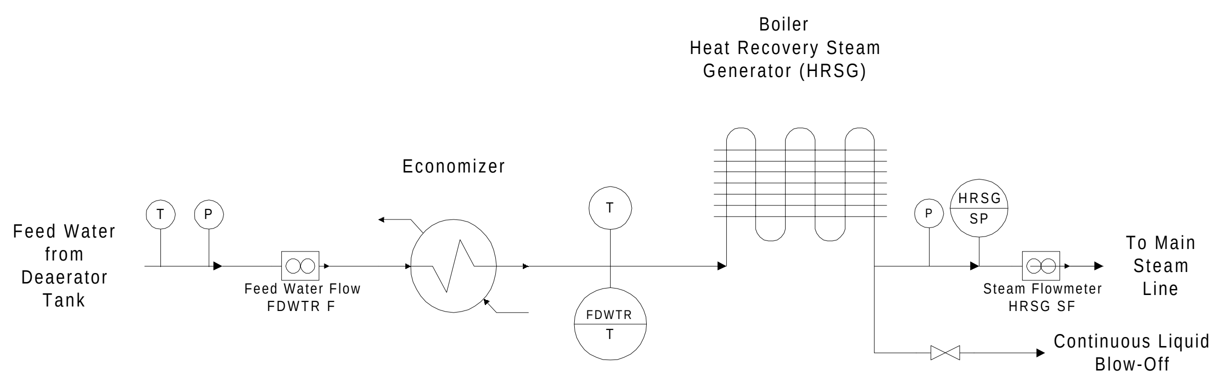


Figure 3 Cogeneration Process Water Flow Diagram

Students are given the process flow shown in Figure 2. This flow diagram is used to show the complexity of a relatively small portion of the steam plant pertaining to the cogeneration unit shown. Using this figure students are guided through the combustion process and the production of steam and electricity. Also shown on this figure is the approximate position of the process measurement equipment that they will be examining on their site visit.

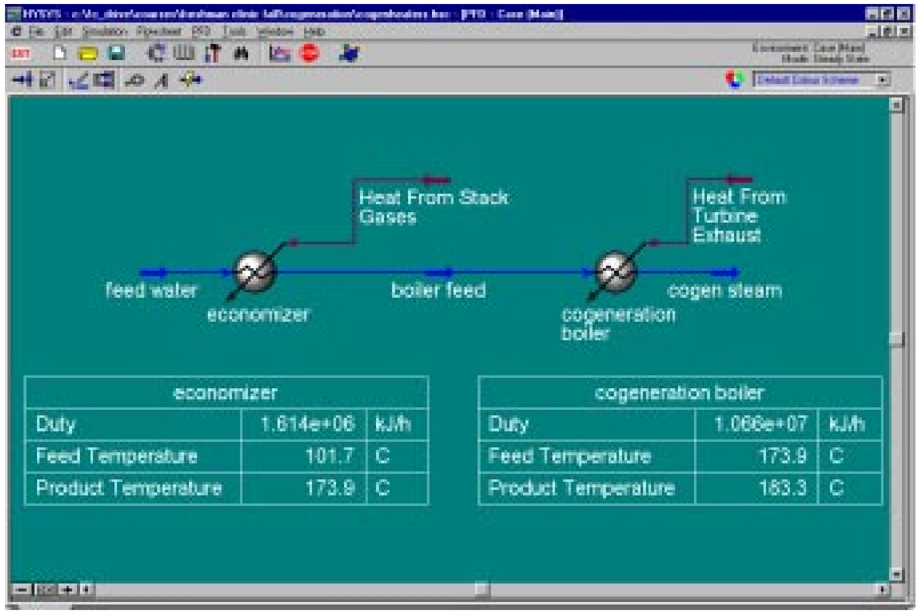


Figure 2 is a very complex process flow diagram for freshman engineers, and a second figure is shown of only the steam production side of the cogeneration unit (Figure 3). Using this relatively simple process flow diagram the students can easily relate their knowledge of boiling water to produce steam to this process.

Site Visit

After the above introduction the students conduct a tour of the facility assisted by upperclassman as tour guides. Students wear personal protective equipment and are given instructions on safety before they enter the plant. Using a special layout plan, given in the appendix, they must identify the equipment and take specific plant readings. On the tour map, shown at the end of the paper, are digitized photographs of all the equipment that they are required to identify. In addition to this equipment recognition, students are required to obtain readings from the process shown in Figure 3. These readings range from manual gauges to digital computer screen readings. Simulations and hand calculations will be based on the readings from the process shown in Figure 3. The table shown below is actual plant readings taken by the students of this process.

Reading	**Computer Notation**	**Reading in High Bay Area**	**Reading Value**	**Units**
Feed Water Flowrate to Cogeneration Facility	FDWTR F	Digital display on brown panel located next to cogeneration boiler.	25.1	1000 lb_m/hr
Steam Flowrate from Cogeneration Facility	HRSG SF	Brown Panel located as given above	21.6	1000 lb_m/hr
Feed Water Temperature	N/A	upstairs, on side of deaerator tank	216	ºF
Feed Water Pressure	N/A	below deaerator tank and above pump	250	psig
Boiler Inlet Water Temperature	FDWTR T	Thermometer on line to boiler	330	ºF
Steam Pressure from Cogeneration system	HRSG SP	1) Brown Panel, under heading Steam Controller Pressure 2) Gauge on side of boiler	150	psig

Upon the completion of this short site visit, students have seen actual process equipment and obtained readings from this process. The students now have a motivation to perform engineering unit conversions and calculations described in the next two sections.

Process Simulation

At the end of the site visit, students return immediately to the computer room and are led through a simulation program of the two heat exchangers. The students start the computer program and select the ASME steam tables as the thermodynamic property package. Next they simulate the two heat exchangers as heaters. After installing each heater they enter the readings obtained in the plant. From this simulation they obtain the temperature of saturated steam, given the temperature and the values of the heat duties of both heaters. A process flow diagram for these two heaters is shown below.

After completing this laboratory, students have experienced two of the activities of the day in the life of an engineer. They have visited an actual plant and then have returned to the computer to simulate a portion of this process.

Homework

For homework, students must calculate by hand the heat duties on both heat exchangers using empirical correlations based on the ASME steam tables. In this assignment, they must show all unit conversions and calculations, and all equations must be dimensionally homogeneous. To aid the students in these calculations, the answers to most of their calculations are obtained from the chemical process simulation printouts. These printouts contain the plant readings in both the English and SI system of units. The only difference between the homework and the simulations is that the boiler has a continuous blow-off stream that was not present in the simulation (See Figure 3.) So the student will obtain agreement between the heat duty on the economizer, but will not get an exact agreement with the simulated boiler heat duty. This descrepancy serves as a check on the integrity of the student's calculations.

This exercise has the advantage of showing to the students the model equations employed by the computer simulation. The students now have the advantage of having seen a process familiar to them (such as boiling water), performed a computer simulation and then conducted hand calculations of the process.

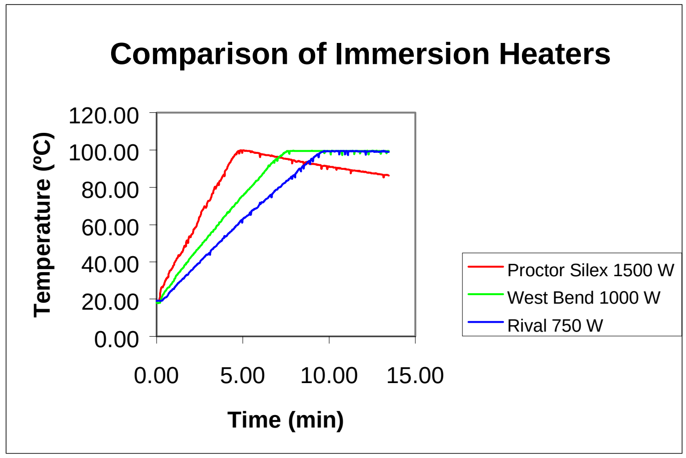
Second and Third Week Experiments

In the next two laboratory sessions four experiments are conducted in which the students use equipment similar to that observed in the cogeneration plant. The experiments performed are:

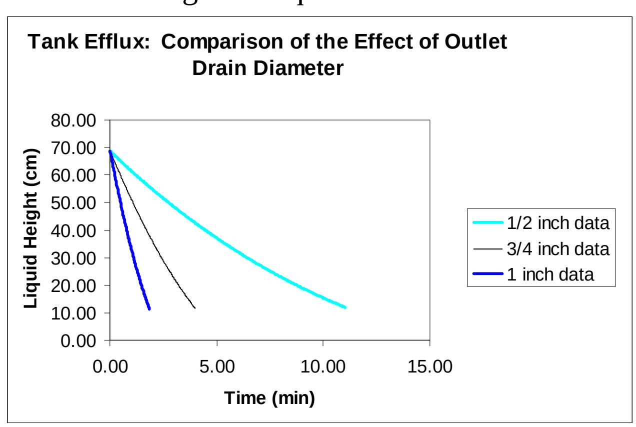
- Flowrate Measurement: Rotameter Operation and Calibration
- Temperature Measurement: Immersion Heaters
- Pressure Measurement: Tank Efflux and Implosion of a 2-L Soda Bottle

The rotameter operation and tank efflux experiments are classic chemical engineering experiments that have been adapted from that of Perna[2]. The implosion experiment employs a pressure gauge, water aspirator and a 2-L soda bottle to graphically show students the effective of vacuum. The immersion water heater experiment is unique in that domestic electric kettles are employed.

In the immersion heater experiment, students measure the temperature of water in an electric kettle heater and the power supplied to this heater. A data acquisition system is used to measure temperature and the power is measured using a Digital Wattmeter. This experiment introduces freshman students to the use of a simple differential equation. An energy balance on this system, assuming the heat losses from the water are negligible is given by $mC_p^{liq}\frac{dT}{dt} = Q_{in} - 0$ Students are able to compare the rated power, power delivered to the immersion heater and the power calculated from the regression of the solution of the differential equation with their data. As you can see from the plot the assumption of negligible heat losses is excellent. The students are able to easily integrate this expression and obtain an engineering prediction of the time required to heat 1 L of water using an immersion heater.



In the tank efflux experiment, students calibrate and use a transducer for pressure measurements. Using a data acquisition system students measure the pressure of water within a 30 gallon tank. As students fill the tank they calibrate the pressure tansducer using a sight gauge mounted on the side of the tank. This sight gauge is similar to that seen by the students on the deaeration tank in the cogen plant. Next students perform three experiments using a 1/2, 3/4 and 1" outlet drain. In this experiment the slope of height as a function of time, obtained from a mass balance $\frac{dm_{tank}}{dt} = \frac{d(\rho A_{tank} h)}{dt} = -\dot{m}_{out}$ The students transform their data to fit an approximate solution of the above equation assuming that there are no pressure losses in the system. A typical plot generated through this experiment is shown here. This assumption results in the solution of the above equation to be a function of the square root of the height of liquid in the tank. Students examine the error in pressure measurement devices by comparing readings from the sight gauge, diaphragm pressure gauge and pressure transducer. This laboratory can be repeated in a fluid mechanics class and the students can analyze this data using pipe flow equations.



Conclusions

All freshman engineering courses should excite the student's interest in engineering. At Rowan we are using a hands-on approach to captivate our students interest. In this paper several innovative experiments based on a cogeneration plant theme are presented. This series of experiments gives students a firm grounding of basic engineering principles. Using an experimental approach in the freshman year both challenges and motivates students to learn the underlying engineering principles of these processes. In addition they have a lot of fun!

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Biographical Information:

C. Stewart Slater is Professor and Chair of Chemical Engineering at Rowan University. He received his B.S., M.S. and Ph.D. from Rutgers University. Prior to joining Rowan he was Professor of Chemical Engineering at Manhattan College where he was active in chemical engineering curriculum development and established a laboratory for advanced separation processes with the support of the National Science Foundation and industry. Dr. Slater's research and teaching interests are in separation and purification technology, laboratory development, and investigating novel processes for interdisciplinary fields such as biotechnology and environmental engineering. He has authored over 50 papers and several book chapters. Dr. Slater has been active in ASEE, having served as Program Chair and Director of the Chemical Engineering Division and has held every office in the DELOS Division. Dr. Slater has received numerous national awards including the 1996 George Westinghouse Award, 1992 John Fluke Award, 1992 DELOS Best Paper Award and 1989 Dow Outstanding Young Faculty Award.

Robert Hesketh is an Associate Professor of Chemical Engineering at Rowan University. He received his B.S. in 1982 from the University of Illinois and his Ph.D. from the University of Delaware in 1987. After his Ph.D. he conducted research at the University of Cambridge, England. Prior to joining the faculty at Rowan in 1996 he was a faculty member of the University of Tulsa. Robert's research is in the chemistry of gaseous pollutant formation and destruction related to combustion processes. Nitrogen compounds are of particular environmental concern because they are the principal source of NO_X in exhaust gases from many combustion devices. This research is focused on first deriving reaction pathways for combustion of nitrogen contained in fuel and second to use these pathways to reduce NO_X production. Robert employs cooperative learning techniques in his classes. His teaching experience ranges from graduate level courses to 9th grade students in an Engineering Summer Camp funded by the NSF. Robert's dedication to teaching has been rewarded by receiving four teaching awards.

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Cogen Tour Guide