Multidisciplinary Experimental Experiences in the Freshman Engineering Clinic at Rowan University

R. P. Hesketh, K. Jahan, A. J. Marchese
C. S. Slater, J. L. Schmalzel, T. R. Chandrupatla, R. A. Dusseau
Rowan University
Glassboro, NJ 08028-1701
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Abstract

All freshmen engineering students at Rowan University are introduced to engineering experiments and calculations through a series of integrated laboratories. These laboratories have the student examine the facets of engineering through fabrication, reverse engineering, engineering measurements, experiment and prototype design.

Introduction:

The school of engineering at Rowan was created through a $100 million gift from Henry and Betty Rowan in 1992 to Glassboro State College [1]. Mr. Rowan is the founder and CEO of Inductotherm, Inc. which has headquarters in Rancocas, New Jersey. Inductotherm is the world's leading induction melting equipment manufacturer with plants located internationally.

The Rowan engineering faculty are taking a leadership role by using innovative methods of teaching and learning, as recommended by ASEE in 1994 [2], 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 Freshman Engineering Clinic has laboratory components for all of the major disciplines. Some institutions have utilized traditional discipline-specific laboratory experiments at the freshman level (Perna, [3]), while others engage students in discipline specific freshmen engineering design projects (McConica 4). One of the NSF coalitions, *ECSEL* has major efforts in freshman design, which have been widely reported (*e.g.*, Dally and Zang [5;] Regan and Mindermann [6]).

Rowan’s engineering program seeks to unify these topics and provide an innovative multidisciplinary team laboratory experience for our engineering freshman. In addition, a major focus of this clinic is on problem solving skills, safety and ethics. In summary these activities (i.) demonstrate the role of laboratory experiments in the engineering decision-making process; (ii) show the interrelationship of engineering and science required for the design and fabrication of a single product; (iii) give stimulating and challenging experiments that relate the laboratory experiments to a consumer product with which most students are familiar.

The freshmen engineering clinic is a two semester course. In the Fall semester a major focus of the course is on problem solving, based on the text by Fogler and LeBlanc [7]. Engineering experiments are tied together using examples of a MAG style flash light, a coffee machine and a temperature alarm circuit. These areas are expanded to give students hands-on experience in engineering measurements.

Flashlight Fabrication and Design

The freshmen engineers start their experience with team building exercise using wooden blocks. Each team is given 30 minutes and a box of blocks to construct the tallest tower. This exercise is followed by a 3 week CAD software session and flashlight fabrication. Each student machined a MAG-style flashlight starting with a 1/2 in. diameter rod of aluminum alloy. The students fabricate the flashlight based on dimensioned drawings and employ both manual and computer controlled equipment. At the end of three 3-hour sessions all 101 students had a working flashlight.

The *shop floor* experience was carried one step further by introducing the students to valuable design and manufacturing principles. Specifically, students were challenged with the question, "How does the performance of a machine affect the overall design of a product?" Thus, the students not only built their flashlights, but afterwards they performed a detailed inspection of their product to determine the quality of each machining processes that they had executed. Using dial calipers, telescoping transfer gages and micrometers, each student accurately measured 25 dimensions of their final product. As they measured each dimension, they entered their data into MS Excel® in groups of four which was added to the data from the remaining groups in the section. With data from 20 flashlights, it was possible to perform simple statistical analyses to determine the accuracy of each machining process. For each dimension the students calculated the range, mean, the standard deviation, s, and, using the definition of a 6s spread, they determined the International Tolerance Grade for each fabrication procedure that they performed.

By executing this inspection procedure, the students were introduced to some fundamental engineering realities. Firstly, the students now understand the difficulties in machining parts to specified tolerances. For example, it was a humbling experience for these would be engineers to discover that the actual variation in the length of the machined battery cavity was 2.750 ± 0.273 inches. Secondly, the students discovered that the performance of a machine is often directly proportional to its cost and complexity. For example, the components that were machined using the CNC machine were found to have the tightest tolerances. Thirdly, the students developed a feel for physical dimensions that are typically encountered in manufacturing. The students now have a physical feel for what 0.001 inch represents. Finally, the students learned how to handle and operate inspection tools. This is a skill that will serve them well in the future.

Having determined the tolerance grade associated with each of the fabrication procedures required to build a flashlight, the students were able to develop a re-designed flashlight that incoming freshman might be asked to build. However, the new design now calls out tolerance specifications for each fabrication procedure required.

The measurement of spatial distances is scaled-up from caliper to building structures in a civil engineering laboratory. Students, in teams of 4, use digital theodolites and triangulation to determine the height of two of the tallest buildings on Rowan's campus. The calculations are first performed using a hand held calculator and then are transferred in a separate exercise to an Excel spreadsheet. Using this spreadsheet they are able to examine the effect of small errors in the measurements of angles and distances.

Cogeneration and Chemical Process Measurements

After reviewing a process schematic of the Rowan University Cogeneration Plant shown in Figure 1, students visit the facility and obtained readings of temperature, pressure and flowrate. Students recorded data from both traditional gauges and thermometers, as well as digital readouts from a data acquisition system employing orifice meters, thermocouples, and pressure transducers. Through this experience students learned about different types of measurement devices and recording data in a "plant setting." An example of an engineering calculation was given to the students was to perform a material and energy balance on the steam production heater using their recorded process variables.

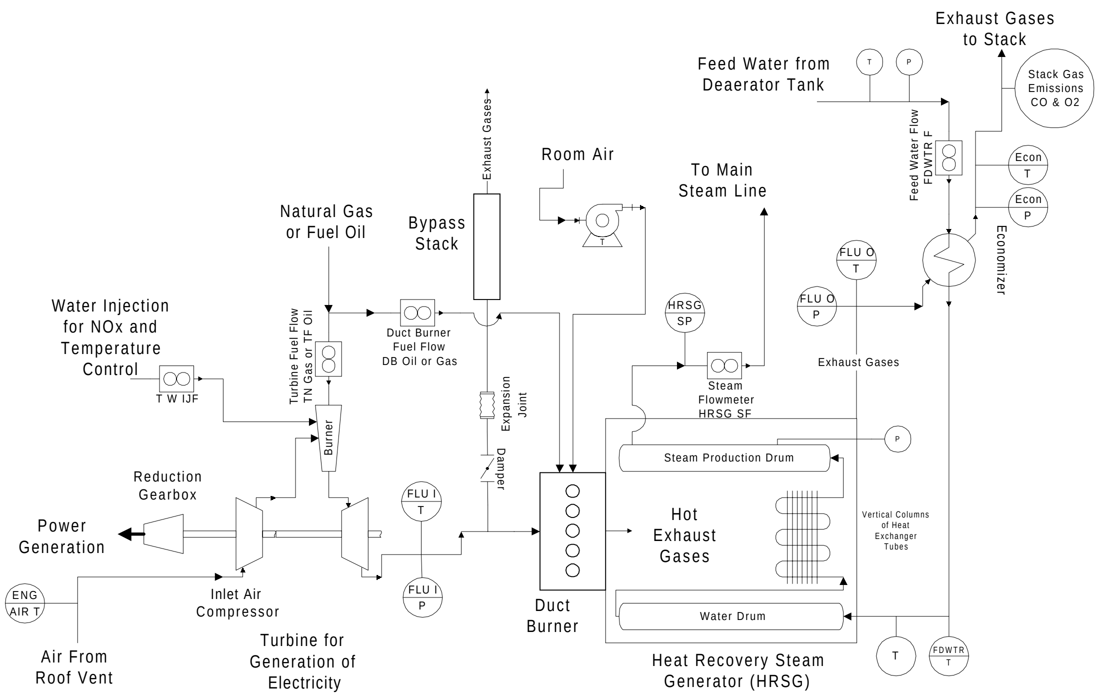

Figure 1: Rowan University Cogeneration Facility

Three experiments are performed to further acquaint students with process measurements and fundamental engineering principles. These experiments include tank drainage from a 30 gallon tank, rotameter calibration, and a 2-L soda bottle implosion. These experiments and their associated calculations and graphs give freshmen hands-on experience in pressure and flowrate measurements.

In all the experiments mentioned above students visually see the process parameter in "action" while taking the respective measurement. They then apply the value obtained to fundamental engineering principles through calculations.

Temperature Alarm System

Students are introduced to the design and construction of an electronic temperature measurement device and alarm system. Basic electrical circuit calculations are given to the student to size resistors and capacitors. With these calculations and a circuit diagram students construct the temperature alarm system. Measurements of resistance and voltage made using a digital multimeter and oscillations in voltage are examined using a oscilloscope. The digital logic states were visualized using red LED's.

Coffee Machine - Reverse Engineering

A common household device, the coffeemaker, is used in both semesters to demonstrate the fundamental principles of engineering (Hesketh [8]). This consumer product exposes students to engineering design through reverse engineering and introduces basic principles of momentum, heat and mass transfer, thermodynamics, electronics, process control, materials, and manufacturing. In Figure 2 a depiction of the coffee machine is given.

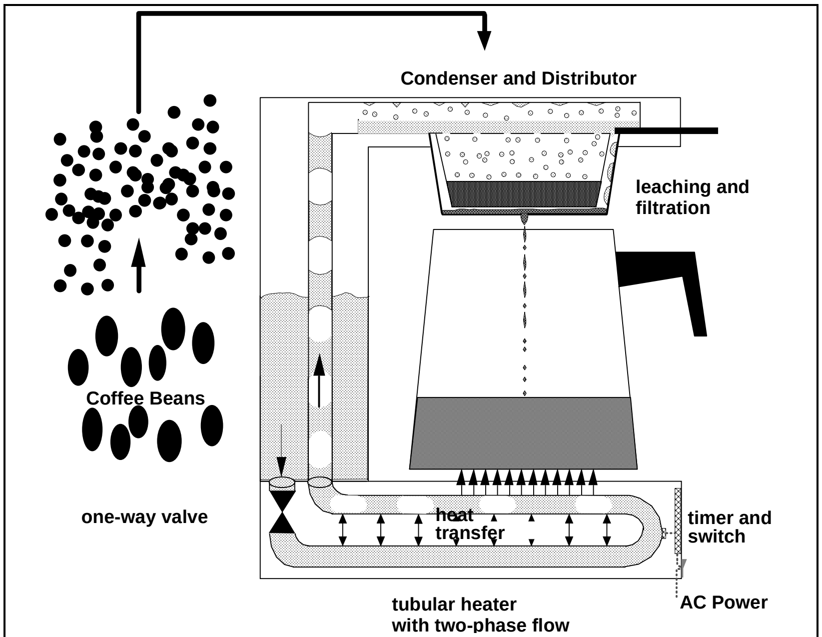

Figure 2: Coffee Machine

In the fall semester the students devote an entire 3-hour lab to reverse engineering a coffee machine. Students in groups of 4 examine the operation of the coffee machine and record data to draw several dimensioned diagrams of the external features of the machine. Next process measurements are taken of the liquid volume and temperature in the receiver vessel (carafe) as a function of time. Finally the students take apart the coffee machine and make measurements to construct drawings of the internals. They summarize their findings in an oral and written report.

In the written report their are several calculations and plots that are required from each group. From the measurement of electrical resistance, temperature and volume of liquid the students perform an energy balance. The students are able to estimate the amount of energy used to heat the water compared to the energy lost to the surroundings.

This short engineering calculation introduces the students to engineering equations employing measured quantities of temperature, time resistance and flowrate. These simple equations also give the students practice in the conversion of engineering units and they are able to see an example of the use of an integral in the calculation of energy consumption by integrating power as a function of time. The students are also taught how to make graphs using a spreadsheet package, Excel.

The final report requires the student to summarize their findings. The written material must detail "how the coffee machine works." They are required to draw a process flow diagram of the process and address other areas of reverse engineering such as mechanical, materials, fabrication & assembly and electrical design.

The students were very creative in their presentations. Many students obtained additional information from the literature, Internet and from phone calls to coffee machine manufacturers. The presentations were required to use visual aids such as posters, transparencies, and devices from the coffee machines.

Spring Semester *Green Coffee Machine Design* Project

In the Spring Semester the Engineering Clinic focuses on the design of a "green" coffee. Students must design a coffee machine that can be marketed as green. Students build on their problem solving skills presented in the previous semester and employ the 5 step heuristic presented by Fogler and LeBlanc [7]. Starting from the question, "What is not green about a coffee machine?" The students define several problem areas such as power consumption, materials of construction, waste reduction, materials recycling and reuse. This was followed by research to gather more information and then a brainstorming session ensued to generate new ideas to solve these problems. A solution was selected by groups of 4 or 5 students and they presented an oral and written proposal. This proposal was approved by the instructor and the group developed an implementation plan to carry-out their design project. Evaluation at each stage of the project was conducted by the group and professor through the use of project review sessions, progress memos and individual journals [9].

A requirement of each new coffee machine design was to test their design assumptions using several experiments developed by the students. These experiments could use equipment developed by the professors for the laboratories described below or were based on equipment constructed by the student.

Six laboratories were developed by the instructors to demonstrate basic engineering principles that are employed in coffee machines. These experiments are summarized in the table below:

Table 1: Summary of Spring Semester Experiments

Experiment	Brief Description
Data Acquisition	Provide a basic foundation of data acquisition including concepts of Input/Output, instrumentation, sampling, analog and digital signals. Introduce the basic tools of data acquisition. Students use DaqView, XLDaqView and voltage and temperature cards.

Materials: Beam Bending Thermal Expansion	Introduction to basic engineering concepts of free body diagrams, forces, moments as well as the material properties of elasticity and coefficient of expansion. Material properties , momentum. In both experiments a data acquisition system was employed to measure linear displacement.
Mass Transfer	Three experiments were conducted to examine the rate of leaching of coffee. The effect of water temperature, particle size and concentration driving force was examined. Concentrations were determined from transmission measurements from a spectrometer and a data acquisition system.
Heat Transfer	Conduction and convection principles were demonstrated through two experiments. The first experiment examined the time required to cool a cup of coffee in three different covered cups (paper, Styrofoam, and a travel mug.) The second experiment examined conduction in three vertical rods (SS 304, Al alloy, and brass) with cooling by natural convection. Temperature measurements were recorded using a data acquisition system and plots were constructed using Excel.
Water Quality	The laboratory introduces students to concepts concerning water quality and major treatment processes used to produce a required water quality. Students have hands on experience on measuring pH, conductivity, turbidity and chlorine residuals for given water samples.
Microcontrollers	Develop simple Input/Output control application. Microcomputer module, breadboards, cabling and software

All experiments expose the students to fundamental engineering units and their conversions, data analysis and graphing using spreadsheets like Microsoft's Excel®, equipment calibration and data acquisition. A detailed example of the materials and environmental laboratories are given below.

Materials: Beam Bending and Thermal Expansion

Freshmen engineering students were introduced to the fundamental concept of how material properties affect the performance of engineering systems. This critical engineering concept was introduced in a two-week module consisting of an interactive lecture, a challenging homework assignment, and a hands-on laboratory experiment featuring PC-based data acquisition. The engineering system chosen to introduce this concept was a transversely loaded beam.

During the lecture, the students derived the function, $y(x)$, that describes the deflection of a simply-supported beam with a point load at the center. A demonstration of the system that they were solving (an 80 inch plastic beam with a physics book resting on top) was at the front of the classroom. In addition to the engineering concepts of stress, strain, and modulus of elasticity, this derivation was a direct application of the scientific and mathematical principles being taught concurrently in Physics and Calculus. Specifically, the derivation required the principles of statics (free body diagrams, SF = 0, SM=0), physical interpretation of the first and second derivative of the beam function, and integration of polynomials.

For homework, students were given the assignment of deriving the following deflection function for a cantilever beam with a point load at the free end:

$$y(x) = \frac{mg}{EI}\left(\frac{x^3}{6} - \frac{Lx^2}{2}\right)$$

where E is the modulus of elasticity, I is the moment of inertia and L is the length. The geometrical configuration studied for homework was identical to the laboratory experiment they would conduct the following week. The objective of the experiment was to determine the modulus of elasticity of 2 different plastic materials by measuring the deflection of end-loaded cantilever beams. As suggested by the above equation, the deflection of a cantilever beam is proportional to the inverse of the modulus of elasticity. Thus, it was possible to determine the modulus of elasticity by measuring the deflection of a beam of known geometry under a known applied load.

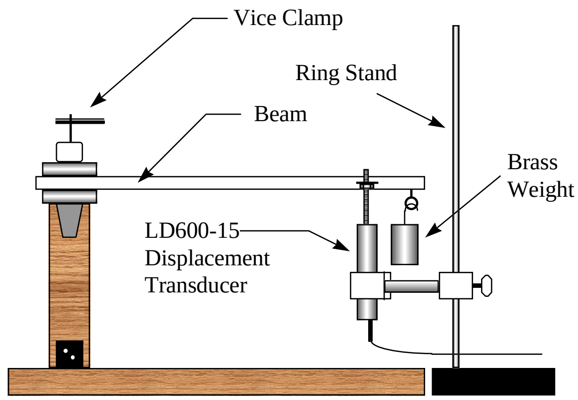

Figure 3. Beam bending apparatus.

Beam Bending Experiments

The beam bending apparatus is shown in Figure 3. The apparatus consists of a wooden stand, vice clamp, brass weights, an Omega LD600-15 displacement transducer, and an IOTek Data acquisition board installed in Dell PC. The LD500-15 produces a voltage output that is directly proportional to the displacement and the applied excitation voltage.

After measuring the beam dimensions using dial calipers and a measuring tape, the students calculated the moment of inertia of the I-beam shown in Figure 4.

The students then had to set up the transducer and data acquisition system. This entailed centering and leveling the transducer, plugging in the data acquisition board, selecting the channels and deriving a gain and offset to convert from measured voltage to inches of deflection.

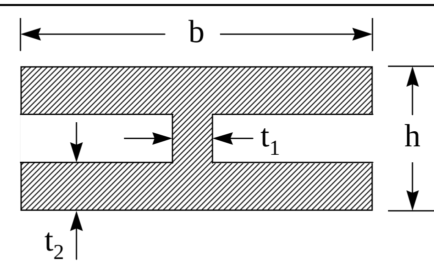

Figure 4. I-beam cross section.

The students acquired data directly into MS Excel and recorded beam deflection in inches as a function of applied load in lb_f. Using the chart wizard, the students made a scatter plot of deflection [in] vs. Force [lb_f]. The students then fit a straight line through the data using the trendline function. Since the measured deflection was proportional to *mg* and inversely proportional to E and I, it was possible to determine the modulus of elasticity, E, from the slope of the deflection vs. force curve.

Thermal Expansion

The previous lecture also included an in-class example of thermal expansion. Using a variable temperature heat gun, a material sample (copper) was heated from room temperature to 300 °F. The length of the sample was measured at 50 °F intervals and the students were able to see how the length varied linearly with the change in temperature.

In the laboratory period, the beam bending apparatus was reconfigured to measure the coefficient of thermal expansion as shown in Figure 5.

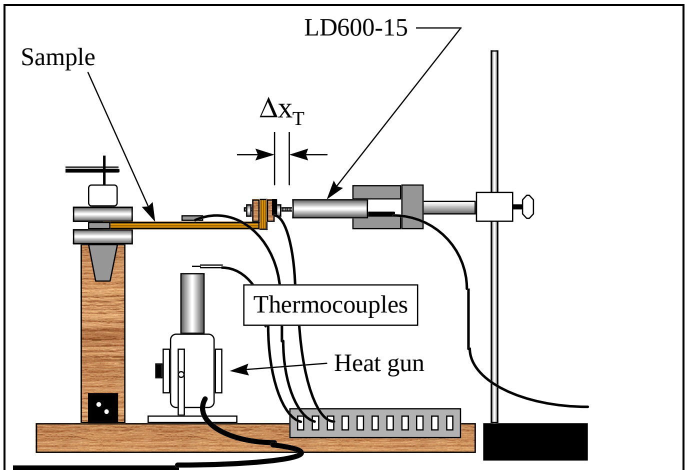

Figure 5. Thermal expansion apparatus.

In this experiment, the change in length of the sample was monitored instantaneously along with the temperature of the sample over a period of 100 seconds. The data was then reduced using MS excel to produce a plot of thermal strain vs. DT. The students then fit a straight line through the data and determined the coefficient of thermal expansion of the material [in/in °F].

Conclusions:

The hands-on Engineering Clinic at Rowan has provides students with a multidisciplinary knowledge related to measurements and they have experienced real world examples of engineering through team-oriented laboratory experiences. These students have gained valuable experience in measurements, design and an introduction to analytical and computational tools. These engineering practice experiences have given students a foundation to their engineering careers.

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