The Competitive Assessment Laboratory: Introducing Engineering Design via Consumer Product Benchmarking

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***Abstract*—In today's quickly changing and increasingly competitive market place, it is imperative that manufacturers keep abreast of the technological advances and design innovations incorporated into competing product lines. The term *competitive assessment* (or benchmarking) has been coined by manufacturers to describe the process of ethically acquiring, inspecting, analyzing, instrumenting, and testing the product lines of other manufacturers. The Competitive Assessment Laboratory at Rowan University is funded by the National Science Foundation (NSF). In the laboratory, multidisciplinary teams of freshman engineering students from each of the four engineering departments perform each of the above tasks on a consumer product. The laboratory contains a series of consumer appliance test stations featuring PC-based data acquisition systems capable of measuring thermocouple and voltage/current signals. Each station is also equipped with mechanical measurement equipment and portable materials testing equipment. In addition to introducing students to the science and art of design, the Competitive Assessment Laboratory enables the faculty to assess the constantly evolving initial conditions under which the typical engineering student enters his or her course of study.**

***Index Terms*—Benchmarking, clinic, competitive assessment, consumer appliance, design, multidisciplinary.**

I. Introduction

THE Engineering Clinic is a course that is taken each semester by every engineering student at Rowan University. In the Engineering Clinic, which is based on the medical school model, students and faculty from all four engineering departments work side-by-side on laboratory experiments, design projects, and research. The solution of these real-world problems requires not only a proficiency in the technical principles, but as importantly, requires a mastery of written and oral communication skills and the ability to work as part of a multidisciplinary team [1], [2]. Table I presents an overview of the themes in the 8-semester engineering clinic sequence. At each clinic level, the underlying concepts of engineering design, student teamwork, and communication skills pervade throughout. The Freshman Clinic II course builds on the Freshman Clinic I course by incorporating measurement techniques in reverse engineering. The Sophomore Clinic builds on the Freshman Clinic by incorporating measurements and reverse engineering in one semester projects. The Junior and Senior Clinics build upon previous clinic levels but focus on a larger scale research/design experience and often involve projects sponsored by industry.

TABLE I
COURSE THEME IN THE 8-SEMESTER ENGINEERING CLINIC SEQUENCE

Clinic Level	Theme
Freshman I	Engineering Measurements
Freshman II	Competitive Assessment Laboratory
Sophomore I	Total Quality Management
Sophomore II	16 Week Multidisciplinary Design Project
Junior and Senior	Multidisciplinary Design/Research Project Emphasizing Entrepreneurship, Product or Process Development, Safety, Environmental Issues and Communication (Written and Oral)

The Freshman Engineering Clinic II course uses an appliance that is familiar to the students and can be used to easily demonstrate engineering principles [3]. This paper focuses on the Freshman Engineering Clinic II (the second of the 8-semester clinic sequence), subtitled Competitive Assessment Laboratory. The objectives of the Competitive Assessment Laboratory at Rowan University are as follows:

1) Provide the launching pad for an innovative 4-yr design curriculum by introducing freshmen to the science and art of design by evaluating the work of practicing designers.
2) Introduce multidisciplinary groups of engineering students to unifying engineering mathematics and science principles, such as differential and integral calculus, fluid mechanics, solid mechanics, thermodynamics, electric circuit analysis, transport, and electromagnetics using the consumer appliance as a test bed.
3) Enable students to determine how scientific principles, material properties, manufacturing techniques, cost, safety requirements, environmental considerations, and intellectual property rights impact the design of a product
4) Allow freshman students to actively participate in a meaningful design effort by instrumenting and evaluating the performance of a consumer appliance.
5) Provide faculty with the means to assess the engineering background of incoming students and address experiential deficiencies via hands-on experience with the tools of the trade.
6) Enable students to improve written and oral communication skills by assigning formal reports and assigning formal presentations.

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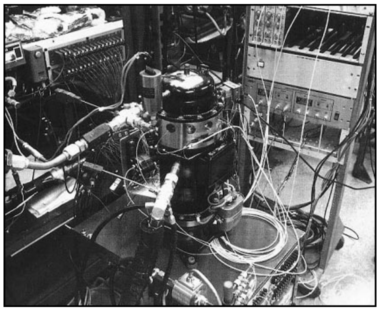
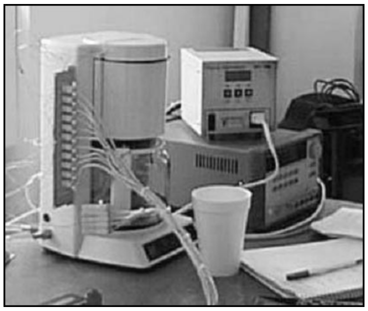


(a)



(b)

Fig. 1. Competitive assessment testing examples. (a) Industry example [4] and (b) undergraduate example of competitive assessment [2].

7) Enable students to engage in cooperative learning as a means to promote thinking skills, communication skills, and teamwork.

II. Focus of the Competitive Assessment Laboratory

The Competitive Assessment Laboratory (funded by the NSF) addresses two related and equally important needs that are critical to the success of any engineering curriculum. The first need is to introduce freshman engineering students to a *realistic* design problem utilizing a vehicle that is commensurate with their limited engineering skills and knowledge. The second need is to enable the engineering faculty to assess the constantly shifting initial conditions under which incoming engineering students enter their course of study. Without an adequate means of assessing the engineering acumen of each incoming student, an attempt to assess the outcomes of any curriculum initiative is futile. The Competitive Assessment Laboratory is aimed at satisfying each of these critical needs.

In the Freshman Engineering Clinic II course, the entire semester is devoted to competitive assessment of a consumer product with a heavy focus on instrumentation and product testing. The term *competitive assessment* (or benchmarking) has been coined by manufacturers to describe the process of ethically acquiring, inspecting, analyzing, instrumenting, and testing the product lines of other manufacturers. Competitive assessment is also the first and most important step in the process that is often called *reverse engineering*. Fig. 1(a) and (b) show an industry example of a refrigeration compressor undergoing competitive assessment testing [4] and an undergraduate example (coffee maker), which will be described in more detail later.

The endeavor of competitive assessment testing is possible at the second semester freshman level because the entire first semester clinic course focuses on *engineering measurements* [5]. Indeed, although not typically encountered until the junior or senior level, computer-based data acquisition has been successfully introduced at the freshman level at Rowan University [2]. Such an approach has also been successful at the Integrated Teaching and Learning Laboratory (ITL) at the University of Colorado at Boulder [6]; wherein, students work in interdisciplinary teams to design, build, and test real products for real customers.

Other institutions have utilized traditional discipline-specific laboratory experiments at the freshman level [7], while others engage students in discipline-specific freshmen engineering design projects [8]. ECSEL, one of the NSF coalitions, has major efforts in freshman design, which have been widely reported [9], [10]. Northwestern University also uses a coffee machine example [11] for their freshman engineering course. Rowan's engineering program seeks to provide an innovative multidisciplinary team laboratory experience for the engineering freshmen. In addition, a major focus of this clinic is on problem solving skills, safety, and ethics. The consumer products expose students to engineering design through reverse engineering and introduce basic engineering principles.

Since it represents the launching pad for a four-year design curriculum, the Competitive Assessment Laboratory fulfills an important niche in the engineering clinic sequence. In addition, it represents the starting point for a constantly evolving curriculum that responds effectively to outcomes assessment. It is impossible to assess the outcomes of an engineering curriculum without first adequately assessing the initial conditions under which the typical engineering student enters his or her course of study. These initial conditions are constantly changing because of changing demographics of incoming students and constantly evolving societal and economic conditions.

In addition to much-needed hands-on experience, the Competitive Assessment Laboratory enables all students to develop a physical feel for the quantities that will form the basis of their theoretical study during the next four years. Upon completion of the course, students are able to answer the questions: How large is a *thousandth* of an inch? How much power (electrical or thermal) is 1 W? What magnitude of flow rate is 1 gpm or 1 lpm? How is energy efficiency defined for a coffee maker, a hair dryer, or an electric toothbrush?

III. Course Structure of Freshman Engineering Clinic II

The Freshman Engineering Clinic II is a 16-week 2-credit course consisting of a 1-h lecture and a 3-h laboratory each week. The course, subtitled Competitive Assessment Laboratory, consists of a semester-long project that introduces design to freshmen engineering students through disassembly, inspection, materials testing, technical assessment, and testing of a consumer appliance. In conjunction with the semester-long project, lectures are given and laboratory experiments are performed to provide students with the rudiments of engineering science and introduce students to the realities of engineering business. The lecture and laboratory content enables students to determine how scientific principles, material properties, manufacturing techniques, cost, safety requirements, environmental considerations, and intellectual property rights impact the design of their product.

The course is divided into four to six sections with a total enrollment of 100 to 120 students. Low-cost consumer appliances are chosen as vehicles for competitive assessment, with each section focusing on a given type of appliance. Multidisciplinary teams of four to five students are given an appliance of a given model to study in detail for the entire semester. Devices, such as coffee makers, humidifiers, hair dryers, bread makers, variable speed drills, electric toothbrushes, etc., operate based on a variety of engineering principles. Each of these devices is unique in the way it utilizes the engineering principles of power generation, fluid mechanics, heat transfer, thermodynamics, electromagnetics, etc., to execute its required objectives. However, each of these devices is manufactured of similar polymers and metals, has similar power requirements (0–1200 W), and must be manufactured at a very low cost and high volume in order to make a profit.

The competitive assessment projects are divided into four phases, namely: 1) nonintrusive testing; 2) disassembly; 3) intrusive testing; and 4) instrumentation of the appliance. The first three phases are combined with faculty-led experiments. The final phase is a series of student-designed experiments.

In the nonintrusive testing phase, students make basic measurements on the product without taking it apart. In this phase they gain a basic understanding of how the product is operated and some basic product specification information. Students start by reading the packaging and operating instructions and then perform a hazard operation analysis (HAZOP) on the appliance. While operating the product, students examine the ergonomics and identify the major features of the unit. Intellectual property information is recorded by the students, and patents are searched using the IBM website.[1] A typical set of nonintrusive measurements for the coffee maker include the maximum volume of the reservoir and coffee carafe, the temperature of the produced coffee, the average flow rate, and the actual power consumed by the unit. The students are requested to prepare a series of formal reports based on their observations and experimental results.

The reports include: 1) nonintrusive testing; 2) disassembly; 3) proposal for competitive assessment experiments; and 4) final report. The final report is cumulative and contains revised sections from each of the previous reports. In this manner, the professor is able to provide feedback on the content and writing style of the students' writing. A similar procedure is given for each of the three formal presentations. Before the first presentation, students are given guidelines similar to those given at professional meetings. All presentations are made using MS PowerPoint to familiarize students with presentation software. In addition to these formal presentations, professors within each section have students run at least one practice session with immediate feedback given by the professor in charge of the section.

During the product disassembly and inspection phase (phases 2 and 3), the student teams disassemble the product, make detailed measurements, create an inventory of all parts, and perform material testing to characterize the materials used to manufacture the product. Material testing consists of hardness testing and differential scanning calorimeter testing of the plastic parts. The students then prepare a detailed set of drawings and submit a report that details the parts, materials, manufacturing, assembly, cost, etc. of their product. The product disassembly phase has been utilized successfully in introductory engineering courses elsewhere [12], [13]. Although disassembling is often referred to as reverse engineering, it actually only represents one small step in the reverse engineering process, which in reality refers to the re-design of a product after developing an adequate technical assessment of current product lines.

The overall competitive assessment project also represents an ideal forum to introduce environmental issues to engineering students of all disciplines. Specifically, students are required to evaluate how environmental issues and regulations affect the product design. Most industries must now consider *design for the environment* (DFE) in their product design and manufacturing processes, thereby requiring environmental responsibility in all engineers [14]. DFE adds unique challenges to all designers and manufacturers.

The next phase in the competitive assessment process is product testing (phase 4). Here, the student teams actively take part in the design process by instrumenting and testing their product. In order to implement this phase, the students design a standard test procedure, conduct a second HAZOP analysis, design and build the experiment, acquire data over the required operating conditions, and analyze the data. Performance data may include instantaneous power consumption, energy efficiency, heat losses, thermal characteristics, flow rates, noise, and vibration. The students then compare the experimental results from the various models of appliances and evaluate the overall performance of each.

IV. Examples of Competitive Assessment Projects

In this section, detail is provided on the experiments performed for three consumer appliances, namely, the coffee maker, hair dryer, and electric toothbrush.

A. Coffee Maker

In the nonintrusive measurements, the students determined the maximum volume of liquid in the carafe and the reservoir, temperatures of the coffee in the carafe, and the approximate power consumption of the unit. Students determined the amount of coffee grounds and particle size that will cause the filter to overflow. In a related measurement they determined how long the no-drip valve can be engaged before the filter will overflow (about 1 min). Professor-supervised experiments allowed the students to determine the optimum water temperature, ground coffee particle size, water flow rate, and the amount of water per mass of ground coffee to produce a good tasting coffee (as judged by the students). The strength of the coffee was measured using a UV-V spectrophotometer to obtain a quantitative measurement.

After the dissection of the coffee machine, students examined the operation of the one-way valve; determined the length, diam-

[1] http://www.patents.ibm.com

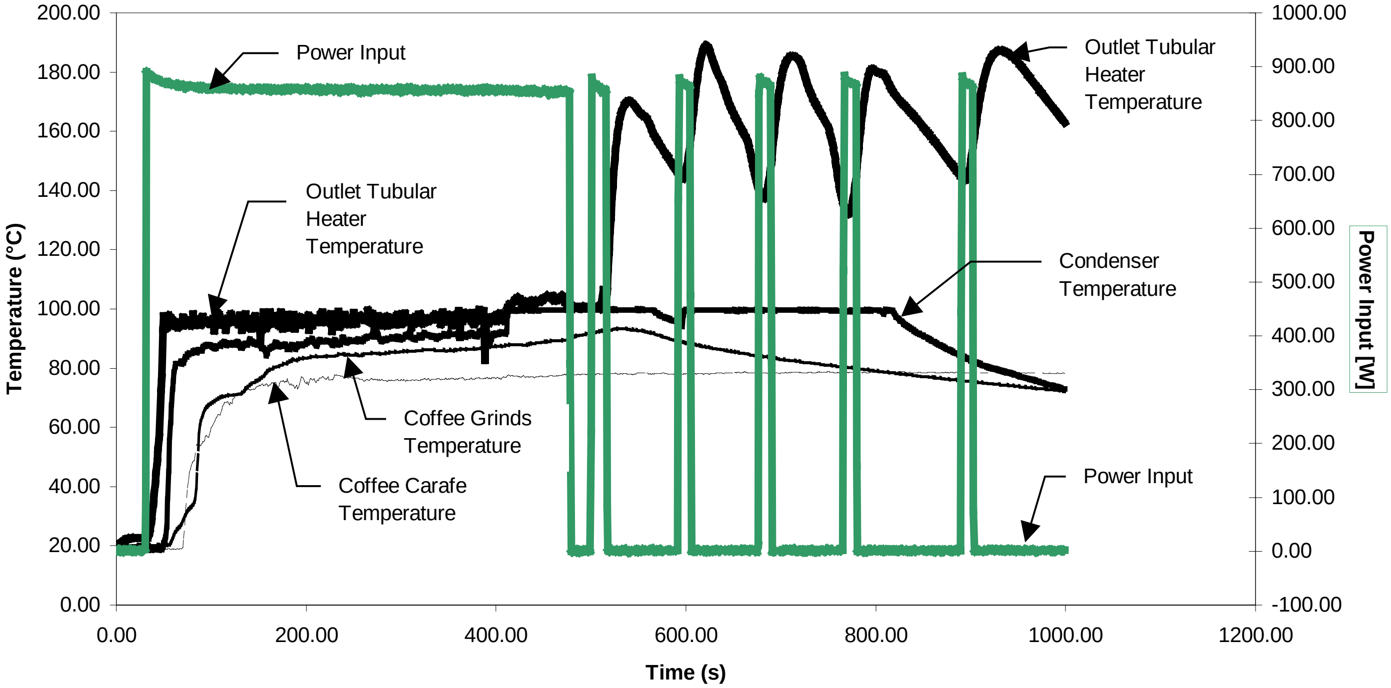


Figure 2 Temperature and Power Input history of a Mr. Coffee PRX 20 Accel Coffee maker.

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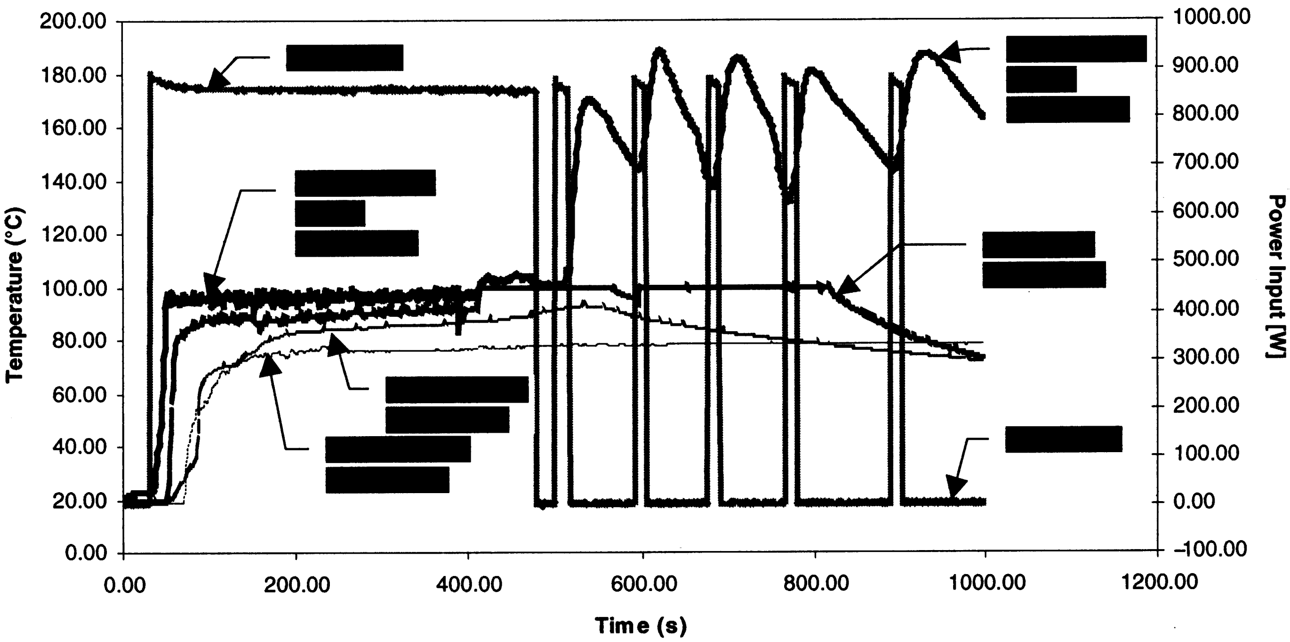

Fig. 2. Temperature and power input history of a Mr. Coffee PRX 20 Accel coffee maker.

eter, and resistance of the resistance heating wire in the tubular heater; and determined the temperature in which the bi-metallic thermal switch triggers. Based on the findings from this phase, students designed experiments to determine the operating specifications of the coffee machine.

The objective of the student-designed experiments was to propose new designs for their coffee machines. Many students investigated methods to reduce heat losses in the riser tube (between the tubular heater and the condenser); examined insulated carafes; investigated new filter designs; and determined the amount of water vaporized.

Finally, all of the student teams instrumented a typical automatic drip coffee machine to determine the specification values of the operating process variables. The coffee makers were operated during a typical brewing and heating cycle, and data were acquired to fully characterize the performance of the appliance. The data were then analyzed to determine the operating design parameters (e.g., flow rates, temperatures, power consumption), characterize the energy losses, and to substantiate (or refute) manufacturers' claims.

For example, one test specimen consisted of a Betty Crocker Series II 12-Cup Automatic Drip Coffee Maker (Model BC-1740), instrumented with 16 thermocouples, one digital power meter, one pressure transducer, and one flow meter [see Fig. 1(b)]. Type K thermocouples were used to measure the temperature at 16 different locations within the machine. A WD-768 Digital Watt Meter, which simultaneously measured power [W], current [A], and voltage [V], was used to monitor the instantaneous energy consumption. The instantaneous water flow rate was measured using an Omega FTB600 ultralow flow sensor, and the liquid reservoir level was measured using an Omega Pressure transducer with a range of 0 to 27 in. H_2O. Data was acquired using a Dell Optiplex GM+ 5133 PC configured with a DaqBoard 100A data acquisition board along with a DBK11A card for voltage inputs and a DBK19 card for thermocouple inputs.

Given the measured data from the above test specimen, the students were able to determine the instantaneous power consumption of the coffee maker during the brewing and heating cycles, the rate of energy transfer to the water during the brewing process, an instantaneous efficiency of the coffee maker during the brewing cycle, and the energy losses during the brewing and heating cycles. Fig. 2 shows typical data obtained by the students. It can be clearly seen from this figure that there is a heat loss in the riser tube and that there is a cycling of the tubular heater temperature with the power input after 450 s. The results of these examples clearly show that it is possible for freshmen engineering students to perform sophisticated competitive assessment testing within the confines of the engineering clinic.

B. Hair Dryer

Another section of students designed and performed a series of experiments on various models of hair dryers. Specifically, students examined the following characteristics of each hair dryer: 1) material properties; 2) sound level; 3) air velocity profile and mass flow rate; 4) air temperature field; and 5) thermal efficiency. Some of these results are summarized below. In general, the students found that in a typical consumer hair dryer, sound levels are dangerously high, and thermal efficiency is surprisingly low.

Materials: Disassembly of each device showed that up to 10 different types of plastic materials are in a given hair dryer. To try to determine the types of polymers used, each team performed tests using a differential scanning calorimeter (DCS). The DCS takes a small sample of plastic and measures temperature versus heat flux. By examining the temperature versus heat flux curve, the students were able to determine melting points

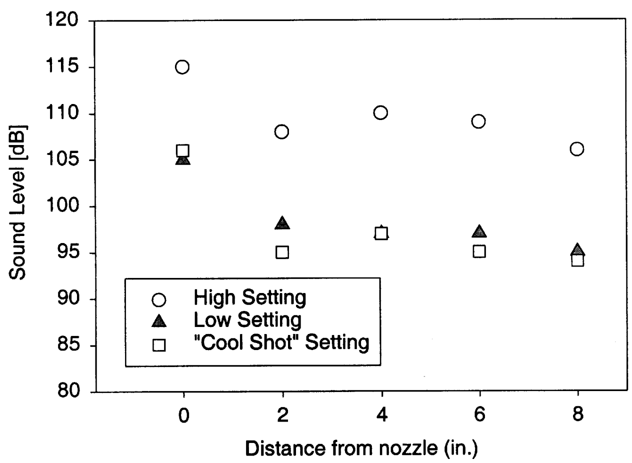

Fig. 3. Sound pressure level of a hair dryer versus distance from nozzle.

and glass transition temperatures. Given these two parameters for each polymer, the students were able to make an educated guess of the types of polymer used in the hair dryer.

Sound Level: A portable sound-level meter was used to develop a three-dimensional map of sound level versus distance from the hair dryer. Fig. 3 is a plot of sound level versus distance parallel to the nozzle exit. The results show that at the nozzle exit, a sound level of 115 dB was measured. At 4 in from the nozzle exit, the sound level still exceeded 110 dB. The students compared these results to guidelines established by the Occupational Safety and Health Administration (OSHA). The results showed that OSHA regulations limit the allowable exposure time to 115 dB to less than 15 min/day. These results suggest that the sound level exposure from the typical daily use of a hair dryer is close to that which could cause permanent hearing loss.

Thermal Efficiency: As with the coffee maker, the students had to determine an appropriate equation to describe the thermal efficiency of a hair dryer. In this case, the useful portion of the overall power requirement was determined to be the instantaneous power associated with the evaporation of water from the user's hair. Combined with the instantaneous electrical power consumption, the following equation for thermal efficiency was derived:

$$\eta = \frac{\dot{m} h_{fg}}{\dot{W}}$$

where η is the efficiency, h_{fg} the heat of vaporization of water [J/kg], $\dot{m}$ the measured instantaneous rate of water evaporation from the user's hair [kg/s], and $\dot{W}$ the measured power consumption [W].

To measure the rate of water evaporation, the students designed an experiment that measured change in mass of a simulated hair sample. The simulated hair sample was attached to the free end of a miniature brass beam. The deflection of the brass beam was measured using an Omega LD600-15 displacement transducer. The output of the LD500-15 transducer, which produces a voltage output directly proportional to the displacement, was directly proportional to the instantaneous mass of the simulated hair.

Having converted displacement versus time to mass versus time, the students numerically calculated the time rate of change of mass using the central difference formula. Results showed that the efficiency of a hair dryer is generally less than 20%. Comparison with the coffee maker results (η approx. 75%) suggests that the coffee maker is an inherently more efficient device. In the case of the coffee maker, the resistive heating element efficiently transfers energy to the water since the water flows directly beside the heating element. In the case of the hair dryer, once the heated air is released from the nozzle exit, the amount of energy that is actually transferred to the human hair is quite low. Much of the energy gets lost to the atmosphere instead of being transferred to the human hair, and some energy is required to heat up the hair to boiling temperature prior to evaporation.

C. Electric Toothbrush

The electric toothbrush [15] is another low-cost consumer appliance used in Freshman Engineering Clinic II. For the nonintrusive testing, students were asked to:

1) record all external features, observe safety features and identify potential hazards;
2) comment on the ergonomics and aesthetics of the design;
3) record external dimensions, make a list of parts, and understand the function of the various parts;
4) make AUTOCAD drawings of the entire toothbrush and the various parts with proper labeling and dimensioning;
5) note all intellectual property rights (like trademark, patent numbers, and registration);
6) conduct a patent search of related patents on the World Wide Web;
7) estimate the manufacturing cost of the product;
8) check environmental feasibility in terms of recyclability and packaging;
9) understand the operating instructions and operate the product;
10) devise and perform an experiment to see how the electric toothbrush compares with a manual toothbrush in removing stains. Is the cost of the electric toothbrush justified in terms of its cleaning capability?
11) recommend any improvements in terms of cost, manufacturing, aesthetics, safety, and environmental issues;
12) conduct a literature survey of electric toothbrushes available in the market.

The experiment to compare the electric toothbrush versus the manual toothbrush is very significant in determining whether the increased cost of the electric toothbrush is justified in terms of cleaning performance. Five teams determined the cleaning time for removing a tomato sauce stain on an enamel bowl. Statistics of the cleaning time were taken and it was found that the mean cleaning time for the manual toothbrush was 43.2 s, and for the electric toothbrush was 47.8 s. The results indicate that the higher cost of the electric toothbrush is not justified. However, this is only a preliminary experiment that can lead to errors, particularly since the force applied to the manual toothbrush varies from person to person. Further investigation into this important issue is needed, and the formulation of more sophisticated experiments is a subject of further work.

For the intrusive testing, two main experiments were conducted as follows.

1) Charging the toothbrush is accomplished by electromagnetic induction. The coil in the toothbrush was evaluated in terms of the number of turns and the voltage across it. The number of turns was then varied to study its relationship to voltage induced. From these data points, least-squares curve fitting was taught, and a curve was estimated to derive a mathematical relationship. The magnetic flux density was also measured using a Gauss meter for varying numbers of coil turns. Again, a least-squares fit was determined.
2) The energy stored in the nickel cadmium battery was measured. The voltage across the battery as a function of time was measured by building a simple resistive circuit through which the battery discharges. From the voltage and resistance, the power of the battery as a function of time was determined. Since the integral of the power is the energy, numerical integration was used to find the energy from the power curve. Students learned how to apply the trapezoidal rule of numerical integration to a practical problem.

In both experiments, the concepts taught in the core courses of electric circuits, electromagnetics, calculus, and numerical analysis were brought together to solve a realistic engineering problem. Freshman students directly see the application of the mathematical concepts they concurrently learn.

In the first experiment, the students observed by making experimental measurements that as the number of turns of wire on the coil increase, the voltage induced also increases. Students determined a straight-line fit by applying their calculus knowledge to compute the parameters of the straight line that minimize the mean-square error. The calculation was carried out by writing a MATLAB [16] program. Similarly, the variation of the magnetic flux density for varying numbers of coil turns was modeled by a straight-line least-squares fit.

In the second experiment, the students found the energy stored in the rechargeable nickel cadmium battery. The fully charged battery was connected across a one-ohm resistor for discharging purposes. The voltage across the resistor was measured at 1-min intervals until the voltage decreases to about 70% of its initial value. From this voltage versus time curve, the power versus time curve was determined merely as the square of the voltage. Numerical integration of the power curve results in the energy stored. The trapezoidal rule of integration [17] was programmed in MATLAB to calculate the energy.

V. Student Benefits and Assessment Results

A. Course Evolution

Since its inception in 1996, the freshman engineering program at Rowan has undergone continuous assessment and improvement. The coffee machine has been used in four successive years, while the electric toothbrush and hair dryer have been used three times. Each year, the concept of competitive assessment is initially introduced through a 3-h exercise with a Mag-style flashlight. This exercise starts with examining the packaging, intellectual property information, and external features of the flashlight. The students then dissect the unit and determine how it works. For homework, students prepare hand sketches showing the mechanical and electrical features of the unit. This exercise was determined by the faculty and the students to be an excellent vehicle to introduce competitive assessment.

In the first year (1996) of the freshman engineering program, the coffee machine was used in both the Fall 1996 and the Spring 1997 semesters [18], [19]. In the Fall of 1996, nonintrusive measurements of temperature, pressure, and flow rate of coffee were performed. From the student assessment of the Fall semester, they rated the flashlight laboratory as very interesting and informative with a rating of 3.1 out of 4, and the reverse engineering of the coffee maker received a rating of 3.2 out of 4. Many students from the Fall semester wrote that they felt the reverse engineering project was a "great project," "useful," and "very fun." The major complaints were that they wanted more time to complete the reverse engineering project and that the requirements for the report were unclear. These positive responses from both the students and the faculty led to the formulation of a semester-long project in the Spring of 1997. The Spring 1997 semester included four 2-week modules on engineering principles (8 weeks) and 6 weeks dedicated to the reverse engineering and design of a green (minimize risk to human health and the environment) coffee machine. The students wrote a final report and made oral presentations of their green coffee machines.

In the summer of 1997, the faculty analyzed the results of the Fall and Spring semesters and decided to concentrate on a single theme of measurements in the Fall semester, and reverse engineering in the Spring semester. The flashlight and nonintrusive measurements sessions were placed in the Spring semesters, and the reverse engineering project was expanded into a 9-week session ending in a final report and presentation. The faculty also believed that the modules were too intensive for themselves and the students. Since these modules were very time consuming, a recommendation to reduce the amount of material was made. A decision was made that students would benefit from additional reverse engineering projects; therefore, three new products were added [15]. A single faculty member would be in charge of one product per section. To facilitate student awareness of the progress on the projects performed by other sections, interim presentations were conducted. Since all sections met at the same time on Monday, these presentations were arranged so that each room had one presentation from each product.

For the next academic year, the Fall 1997 semester was devoted to the measurements theme, and the Spring 1998 semester was devoted to reverse engineering. In Spring 1998, the faculty conducted six 1-week laboratory modules and eight weeks were devoted to the reverse engineering project(s). The laboratory modules were conservation of mass and energy, mechanics of materials, data acquisition, and environmental issues. The software modules were MATLAB and AutoCAD. The students needed to begin work immediately on their reverse engineering projects, but they also needed the information that was given in the laboratory modules. To solve this problem, an innovative rotation scheme was instituted. In this scheme, each team sent a member to each of the four laboratory modules. As a result, after

TABLE II
STUDENT SELF-ASSESSMENT RESULTS (1 – POOR, 2 – FAIR, 3 – AVERAGE, 4 – ABOVE AVERAGE, 5 – EXCELLENT). BASED ON 60 STUDENTS

Question or Statement	Mean	Standard Deviatio n	Median
Students self–rated ability to understand basic measurement techniques and devices	4.13	0.60	4.00
Students self–rated ability to use data acquisition system to obtain engineering data	3.82	0.69	4.00
Students self–rated ability to analyze data by using graphs and observing trends	4.22	0.79	4.00
Students self–rated ability to use Powerpoint for creating effective presentations	4.42	0.66	5.00
Students self–rated ability to prepare reports of actual engineering projects	4.10	0.77	5.00
Students self–rated ability to disassemble and understand the workings of a product	4.18	0.64	4.00
Students self–rated ability to use a problem solving strategy on real engineering problems	3.96	0.66	4.00
Students self–rated ability to apply knowledge of mathematics and science to engineering problems	4.14	0.56	4.00
How does reverse engineering help in introducing engineering principles?	4.11	0.70	4.00
How does reverse engineering help in introducing engineering design?	4.00	0.80	4.00
Considering everything, how would you rate this course?	4.02	0.65	4.00

the first week of modules, every team had an "expert" in each of the four engineering principles areas and could begin work using this information. For the remaining engineering principles modules, a different team member was sent to each module so that after the fourth module week, all team members had completed every engineering principles module. This technique also encouraged students to help teach each other these engineering modules and promoted cooperative learning.

Using this semester-long approach, the students no longer complained that they did not have enough time to complete their reverse engineering project. The students did find the rotation scheme to be confusing, but this confusion could be resolved by having the professor assign the student rotation schedule. The professors commented that the six modules were not completely incorporated within the reverse engineering projects and that more relevant information could be gained by students if the engineering principles modules were directly related to their projects. Faculty also expressed a desire to have more contact with their section of students.

For the academic year 1998/1999, the Fall 1998 semester continued on the theme of measurements. In the Spring of 1999, the engineering principles modules were integrated into the reverse engineering project. Using this approach, each of the engineering principles modules was related directly to the reverse engineering project. An added benefit of this scheme was that the faculty were in contact with their students for the entire semester. No changes were made to the course for the Spring 2000 semester.

B. *Quantitative Assessment Results*

Table II shows quantitative results based on feedback from 60 students in the Spring 2000 semester. For each question or statement, students were asked to give a score ranging from 1 (poor) to 5 (excellent). The mean, standard deviation, and median are recorded in Table II. Students consistently gave an overall rating of about 4.0 for various aspects of the course. From Table II, one can see that students commented positively on the use of reverse engineering projects to teach engineering principles and engineering design. From the emphasis of measurements in the Fall semester and their use in experiments in the Spring semester, students felt that they had a very good understanding for using basic measurement devices, such as thermocouples, flow meters, pressure transducers, voltage/current multimeters, etc. Students also felt that they were very capable of preparing written reports and oral presentations.

The next assessment measurement was made by asking 50 sophomore students in the Spring 2000 semester about how beneficial and helpful the freshman clinic experience is for the sophomore clinic. Students gave a score of 1 for not beneficial, 2 for marginally beneficial, 3 for beneficial, and 4 for highly beneficial. The mean score was 3; the standard deviation was 0.69; and the median score was 3; indicating a beneficial freshman clinic experience. Senior students were asked whether the freshman clinic experience was a benefit to subsequent courses (excluding subsequent clinics) and to list those courses. The courses that were listed include fluid mechanics, circuits, statics, solid mechanics, electronics, thermodynamics, dynamics, and mathematics for engineering analysis.

A consistent comment from freshmen was that the freshman engineering clinic is very time-intensive and should be worth more than two credit hours. Currently, there are two contacts per week; a 1-h classroom session and a 3-h laboratory session. In general, they requested more lab time to conduct experiments. These comments are tremendous affirmations of the value that students have placed on conducting hands-on freshman engineering laboratories.

In comments on the "most important thing learned in the course," many students commented positively on teamwork, giving presentations, writing reports, relating engineering principles to a commercial product, and using cooperative learning. Industry has always requested that engineering schools produce engineers with a higher level of communication skills. The authors firmly believe that having students make engineering presentations and write engineering reports every semester will meet this challenge. Cooperative learning is very significant since research has shown that students learn better when working together, and students are encouraged to work in teams which is necessary in the real world [20]–[22].

VI. Summary and Conclusion

The Freshman Engineering clinic has enabled faculty to introduce students to engineering design and to stress the importance of working in multidisciplinary groups. Students benefit in a variety of ways that include:

1) hands-on exposure to the engineering principles behind a familiar consumer appliance;
2) computer skills in terms of using AUTOCAD, MATLAB, and the Web;
3) an understanding of safety, aesthetics, cost, environmental issues, and efficacy of a product;
4) an introduction to intellectual property issues and patents;
5) an opportunity to design their own experiments;
6) the ability to do a statistical analysis;
7) the ability to apply engineering and mathematical principles to experiments relating to the consumer appliance;
8) training in effective oral and written communication.

The assessment results of Table II are very encouraging in that: 1) students understand measurement techniques; 2) realize that reverse engineering is significant in introducing engineering principles and for engineering design; and 3) achieve an enhancement of written and oral communication skills.

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