Session 2225

The Sophomore Engineering Clinic: An Introduction to the Design Process through a Series of Open Ended Projects

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Abstract

A major objective of the Sophomore Engineering Clinic I, which is the third course in an 8-semester design sequence taken by all Rowan University engineering students, is to introduce students to formalized engineering design techniques employed by the various engineering disciplines. This objective is accomplished by introducing students to a Total Quality Management (TQM) approach to design. Using this approach, multidisciplinary student teams organize engineering specifications using the House of Quality, develop several conceptual designs, evaluate these designs using Pugh's method, and perform guided iteration to identify optimum designs. Following their formal introduction to TQM, all engineering students complete four 3-week open-ended design projects sponsored by each of the four engineering departments. The mechanical engineering project focuses on design of a mechanism. In this project student teams design, analyze, fabricate, instrument and test a fully operational can crusher device. In the chemical engineering project, students evaluate the use of Kevlar (poly p-phenylene terephthalamide) fiber as a unique potential replacement for steel in highway bridges. Students perform tensile testing on Kevlar fibers and perform statistical analyses to propose a set of treatment conditions that will produce the optimal fiber for the proposed bridge. The civil engineering module focuses on the design of a sheet pile wall. Using laboratory experiments, students are introduced to the concept of flow nets and a seepage tank is used to demonstrate seepage flow around a sheet pile wall. Students perform a numerical simulation of fluid flow with MS Excel utilizing the finite difference approach and the numerical solutions are compared to actual values measured in the laboratory. Using these results, students design the most economical sheet pile wall section for a given set of conditions. Finally, in the electrical and computer engineering module, students are given the task of designing an analog filter that forces the frequency response of walkman style headphones to be flat or independent of frequency. Students measure the frequency response of the headphones in the laboratory, produce a design of the equalizer filter, build the equalizer filter and verify that the overall response is independent of frequency (flat). The performance of the design is calculated as the mean-square deviation from a flat response, which is done by writing a computer program in MATLAB.

Introduction

In 1992, local industrialist Henry M. Rowan made a generous donation of $100 million to the then Glassboro State College to establish a high quality engineering school in southern New Jersey. This gift has enabled the university to create one of the most innovative and forward-looking engineering programs in the country.

The College of Engineering at Rowan University is composed of four departments: Chemical Engineering; Civil Engineering; Electrical and Computer Engineering; and Mechanical Engineering. Each department has been designed to serve 25 to 30 students per year, resulting in 100 to 120 students per year in the College of Engineering. The size of the program has been optimized such that it is large enough to provide specialization in separate and credible departments, yet small enough to permit the creation of a truly multidisciplinary curriculum in which laboratory/design courses are offered simultaneously to all engineering students in all four disciplines. Indeed, the hallmark of the engineering program at Rowan University is the multidisciplinary, project-oriented Engineering Clinic sequence.

The Engineering Clinic

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 require not only a proficiency in the technical principles, but, as importantly, require a mastery of written and oral communication skills and the ability to work as part of an multidisciplinary team[1,2] Table 1 contains an overview of course content in the 8-semester engineering clinic sequence. As shown in the table, while each clinic course has a specific theme, the underlying concept of engineering design permeates throughout [3].

Table 1. Overview of course content in the 8-semester Engineering Clinic sequence.

Year	*Clinic Theme (Fall)*	*Clinic Theme (Spring)*
Freshman	Engineering Measurements	Competitive Assessment Laboratory
Sophomore	Discipline Specific Design Modules	16-week Multidisciplinary Design Project
Junior	Product Development	Process Development
Senior	Multidisciplinary disciplinary Capstone Design Project	

This 4-year, 20-credit design sequence offers students the opportunity to *incrementally* learn the science and art of design by continuously applying the technical skills they have obtained in traditional coursework. For example, in the Freshman Engineering Clinic II, students begin their formal study of the design process in the Competitive Assessment Laboratory. This NSF-funded laboratory introduces freshmen to the science and art of design by allowing students to technically evaluate the work of practicing engineering designers. In the freshman course, students dissect, instrument and test consumer products to determine how scientific principles, material properties, manufacturing techniques, cost, safety requirements, environmental considerations and intellectual property impact the design process. Figure 1 shows a student experiment designed to measure the thermodynamic efficiency of a typical household coffee maker[4].

Figure 1. Competitive Assessment Experiment

Sophomore Engineering Clinic I

Having studied in detail the work of practicing engineering designers, the students are ready to embark on their careers as designers. To meet this objective, in the Sophomore Engineering Clinic I, all engineering students complete four compact, open-ended design projects sponsored by each of the four departments. Each module demonstrates the design principles inherent in various classes of design problems. As outlined in table 2, during the course of the semester each student completes the following modules: design of a product, design of a process, design of a structure, and design of a simulation. In the Fall 1998 semester, sophomore engineering students from each of the four departments completed the following four 3-week design modules: design of a can crusher, design of a sheet pile wall, design of a kevlar heat treating process, and an analog filter design.

Table 2. Design modules in the Sophomore Engineering Clinic I (Fall 1998).

Design Problem	*Design Module*	*Department Sponsor*
Product	Design of a Can Crusher	Mechanical Engineering
Software Simulation	Design of an Analog Filter	Electrical and Computer Engineering
Structure	Design of a Sheet Pile Wall	Civil Engineering
Process	Deisgn of a Kevlar Heat Treating Process	Chemical Engineering

While there are aspects unique to each of the design modules, the unifying aspects of design theory are stressed throughout. This objective is accomplished by introducing students to a Total Quality Management (TQM) approach to design. Using this approach, multidisciplinary student teams organize engineering specifications using the House of Quality[5], develop several conceptual designs using various brainstorming techniques, evaluate these designs using Pugh's method[6], and perform guided iteration to identify optimum designs. Following their formal introduction to TQM, all engineering students complete the four 3-week open-ended design projects sponsored by each of the four engineering departments. Each of the 3-week design modules are described below.

Design of a Product: The Can Crusher

The objective of the 3-week design module sponsored by the Department of Mechanical Engineering is to introduce students to the production realization process with emphasis on design and development of a mechanism. The product realization process emphasizes the various design stages including concept design, configuration design and parametric design[7]. Teams organize engineering specifications using the House of Quality, develop several conceptual designs using the objectives tree, evaluate each conceptual design using Pugh's method, and perform guided iteration to identify the optimum design. Finally, they build, instrument and test a functional prototype. In the Fall 1998 semester, students were asked to design, develop, fabricate and test a can crusher.

The entire mechanical engineering module is approached from a TQM standpoint. Specifically, students identify the customer attributes (CA's) associated with a "quality" can crusher. Next, they use the House of Quality to map the vague, non-technical customer attributes into real engineering characteristics (EC's). The students also learn the valuable lesson of time and resource constraints since the development of a "quality" device is inherently constrained given the three-week time period. Currently, the materials available for the mechanism design module have typically consisted of aluminum flat, angle and square stock, lumber and various pins, bushings and fasteners.

In addition to introducing students to the product realization process, a major goal of the engineering clinic sequence is to provide design projects that reinforce the engineering science principles that are being taught concurrently in the more traditional engineering courses. Developing a real mechanism in the first semester of sophomore year is an ideal fit with any engineering curriculum. Using principles from Statics, each team designs their mechanism to achieve a desired mechanical advantage. Once the static analysis is complete, the student teams use the principles of Solid Mechanics to determine whether the mechanism will fail under the nominal loading conditions. Each two-force member is designed so that the tensile stress does not exceed the yield strength and that the compressive forces did not exceed the critical buckling load. Each pin connection is designed so that it does not fail in shear and each bearing surface is analyzed to determine whether it would crush under the pin loading. Clearly, some iteration and tradeoffs are encountered during this parametric analysis stage. If, for example, a compressive link is determined to exceed the critical buckling load, this might require a change in the linkage scheme, which in turn requires another iteration in the static analysis.

To assist students in performing these calculations, tutorials are provided via the Internet. These tutorials include examples from Statics and Solid Mechanics as well as definitions and material properties. Students are allowed to use the prototype fabrication facility only after they have completed their design calculations. In other words, no one is allowed to build anything by trail and error alone without going through the design process.

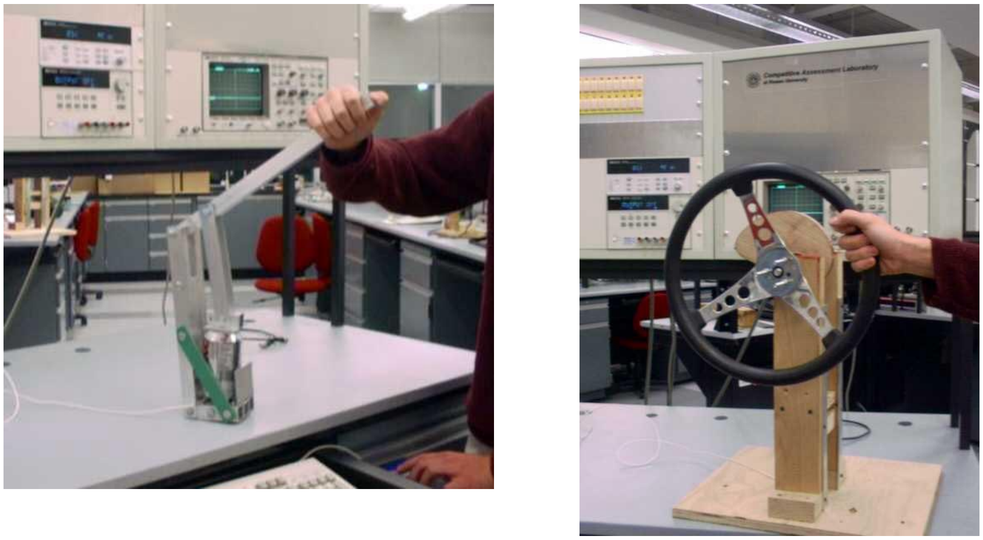

Figure 2. Final testing of several can crusher prototypes.

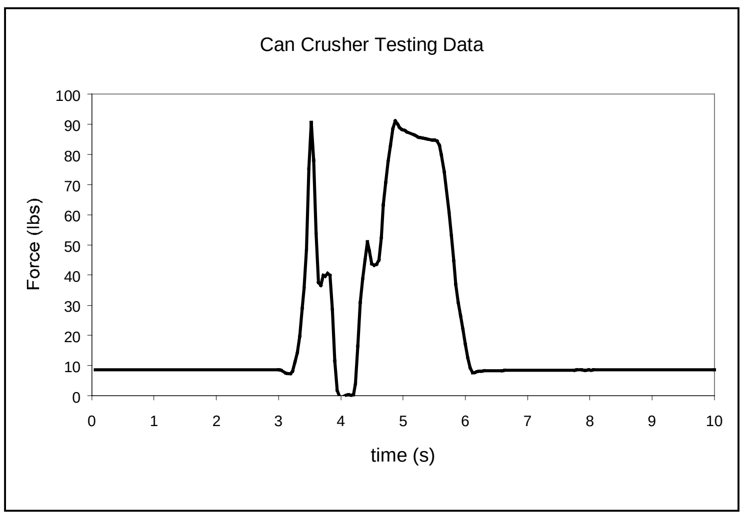

Figure 3. Instantaneous can crushing force.

The final step in the parametric design stage is testing. To determine if the mechanism meets the force specifications, the device is fitted with a load cell to measure the output force. Static tests are performed to determine the static output force as a function of input force. These measurements are compared to the calculated mechanical advantage. In addition to static force testing, an instantaneous force vs. time curve is generated to determine the actual output force of the device under operating conditions. As shown in Fig. 3, the instantaneous force always showed two distinct peaks. The first peak corresponds to the initial impact loading on the can. The force then quickly drops as the can buckles and loses strength. The force then builds up again as the can become compacted. The students did not expect this phenomenon and, thus, did not incorporate it into their design. The students discussed future refinements in which their designs might be tailored toward the actual force vs. time curve, instead of designing for a static load of approximately 200 lb_f.

Design of a Software Simulation: Analog Filter

The 3-week module sponsored by the Department of Electrical and Computer Engineering emphasizes the simulation aspect of design in the form of a practical analog electrical filter design[8,9]. The background to the problem is that a potential source of hearing loss is due to excessive noise from portable "Walkman" style equipment with headphones. This noise is dominant at certain frequencies [10]. The existing equipment includes only a relative volume control which is not frequency selective. A useful accessory would be to provide an equalizer filter that attenuates the dominant frequencies and boosts the suppressed frequencies all to an acceptable level. The resultant response would be constant across all frequencies and at a level that does not damage hearing. This accessory could be built in to the headphone. The objectives of the module are to:

- provide a structured introduction to a focused electrical design methodology for the purposes of solving a real-world problem,
- introduce programming/simulation tools (C++ and MATLAB) for verifying the design and computing a performance measure,
- introduce the student to electrical test/measurement equipment, and
- enhance communication skills.

In the first week, the students are introduced to the principles of design, to the actual problem at hand and to the software simulation tools and measurement techniques. The frequency response of the headphones is measured and a plot of this response and the proposed equalizer filter response is generated in MATLAB. A simple lowpass filter circuit is built and the frequency response measured. This is verified using MATLAB. In this way, students understand the basic filtering mechanism before proceeding to the more complicated equalizer design. During the second week, a detailed design of the equalizer is formulated as a parallel combination of a lowpass and highpass filter. The equalizer circuit is implemented and the frequency response measured. During the third week, the design and is evaluated and an error analysis is performed. The obtained equalizer response is combined with the response of the headphone to get an overall response, which should ideally be constant over all frequencies. This overall response is obtained using MATLAB. The mean-square and absolute errors between the ideal response and the obtained response is calculated as the performance measure using both MATLAB and C++. Also, students are asked to analyze the error versus frequency and recommend how the design can be improved to achieve a lower mean-square and absolute error.

A written report describing the entire exercise is submitted at the end of the module. This will include all software programs, the quantitative error analysis and professional drawings of all circuits. Figure 4 shows the response of the headphone and the equalizer response which when added would be constant at 0 dB.

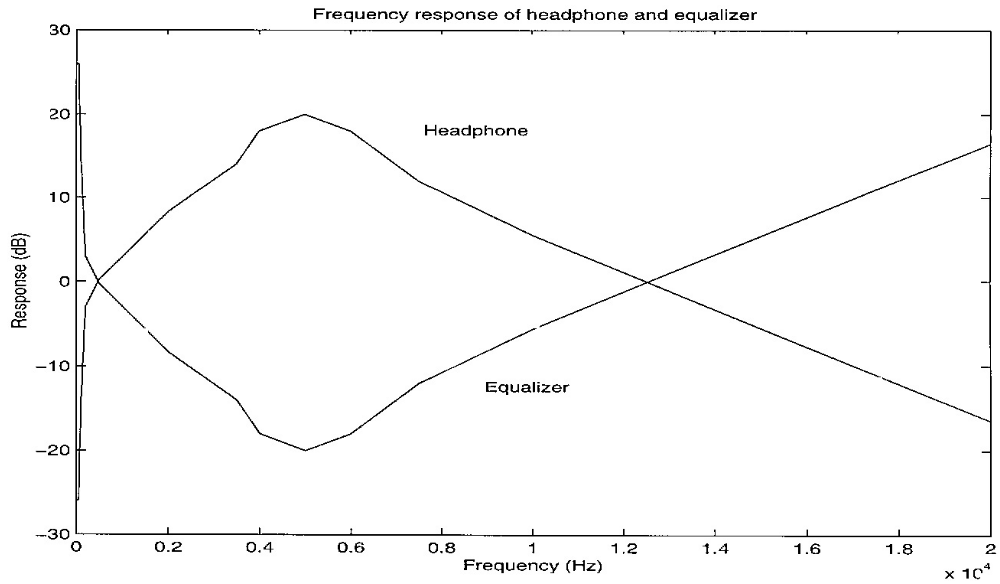

Figure 4. Frequency response of headphone and filter.

Design of a Structure: Sheet Pile Wall

The 3-week module sponsored by the Department of Civil Engineering focuses on the design of a sheet pile wall. The sheet pile wall was chosen to demonstrate and reaffirm the engineering course work the sophomore students have already completed or are in the process of completion. The main objectives of the module are to:

- use current technological tools to design a structure,
- analyses of a real-life problem using engineering principles,

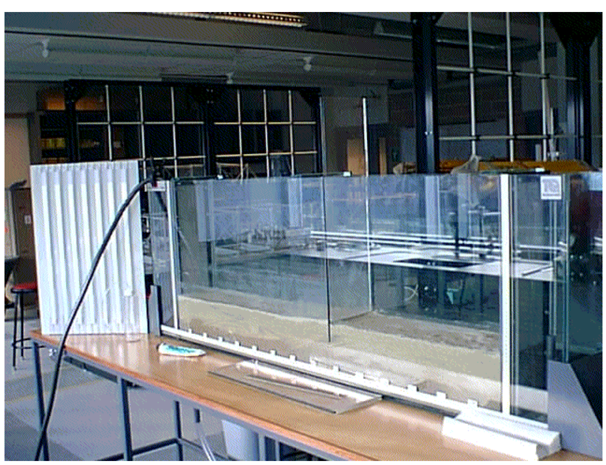

Figure 5. Seepage tank experiment.

- evaluate the economics of design,
- encourage cooperative learning, and
- communicate design solutions effectively.

The students are presented with a real-world engineering problem for which the most economical design solution has to be determined. In the module, students are encouraged to work in groups. Cooperative learning accomplishes shared learning goals as and maximizes their own and each other's learning. In addition, group work simulates consulting engineering environments.

In the first week of classes, the students are introduced to fluid flow around a sheet pile wall. At present, the Civil Engineering laboratory houses a seepage tank that is used to demonstrate flow pattern around a sheet pile wall. Piezometers placed at the upstream and downstream end are used to measure the pressure head at various points. The students perform a constant head permeability test to measure the coefficient of hydraulic conductivity of the soil used in the seepage tank (See Fig. 5). In the second week, the students are introduced to the concept of flow nets. Graphical techniques, as well as spreadsheet solutions utilizing the finite difference approach are introduced. The students perform a numerical simulation of fluid flow around a sheet pile wall using Excel. The results of a calculation are shown in Fig. 6. The model dimensions used are the same as that used in the seepage tank. The numerical values of total head are then compared to the actual measurements made in the laboratory. If the results obtained from their numerical simulations differ greatly from the solutions obtained in the laboratory, students have to provide reasons on why this is so. In the third week, the students are introduced to the design of the sheet pile wall. The design performed should be the most economical solution to the problem.

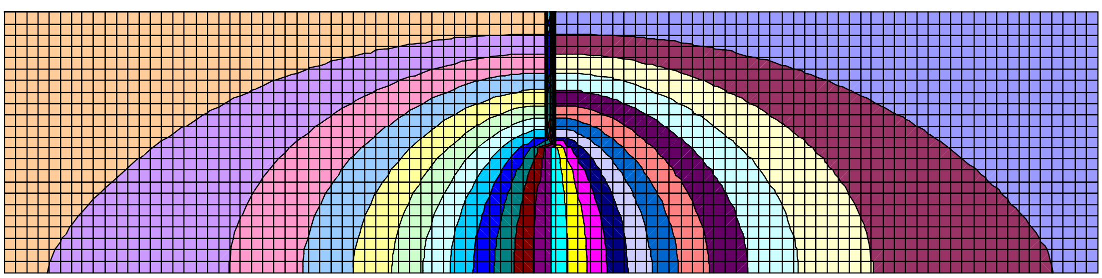

Figure 6. Calculated distribution of total head around a sheet pile wall.

Finally, to analyze their written communication skills, the students are posed with an ethical problem in which they are required to write a letter to persuade the client to use clean sand rather than clay as the backfill material even though there is a significant difference in cost. In the letter, they are required to address the following ethical issues:

- Where does the responsibility of the engineer end and the construction site contractor begin?
- Should the engineer allow construction workers to endanger their lives by not using the safer design?
- If design codes do not require you to use a clean sand backfill, would social responsibility come before legal liability?

Design of a Process: Kevlar Heat Treating

In the module sponsored by the Department of Chemical Engineering, students work in multidisciplinary teams and gain an introduction to materials testing, polymer science, computer simulation, and basic experimental statistics. They also receive their first introduction to design of a process. Specifically, students are asked to evaluate the potential use of Kevlar (in fiber-resin composites) as a replacement for steel in bridge building applications and to recommend processing conditions for the fibers.

In the first sessions, a brief lecture is given on Kevlar and the relationship between compressive and tensile strengths. Each team is given a sample of as-received or heat treated Kevlar. Each team member is assigned a different type of report to present as the primary product of his or her module. The report formats used include a summary report, an operations manual, a letter to the University president, an oral presentation; and a marketing pamphlet (geared toward city planners and architects). The remainder of the class is spent in the laboratory mounting fiber samples for subsequent testing.

In the second session, the students are introduced to the fundamentals of experimental statistics, including the determination of confidence intervals and the elimination of erroneous data by the q-test. They are given individual take-home examinations to reinforce these points. The remainder of the section (and some considerable time beyond) is spent tensile testing the fibers using an Instron Ultimate Testing Machine.

The final session begins with one member of each team giving a 10-15 minute oral presentation to the class. At the conclusions of the presentations, the class moves to a computer laboratory and simulates the process used to heat the fibers. Using HYSYS, the students simulate a furnace that heats nitrogen to 700K. They use this simulation to determine the energy requirements to operate the furnace for eight hours. The students then must contact the local electrical supplier to find industrial rates for power and include it in the summary reports.

Conclusions

A major objective of the Sophomore Engineering Clinic I is to introduce students to formalized engineering design techniques employed by the various engineering disciplines. This objective is accomplished by introducing students to a Total Quality Management (TQM) approach to design. Since all engineering design projects are intended for a specific customer, who associates a certain set of attributes with a quality product, the TQM approach is applicable to all of the design projects completed in the Sophomore Clinic.

A second objective is to provide design projects that reinforce the engineering science principles that are being taught concurrently in the more traditional engineering courses. After a common freshman year, the curricula of the four engineering departments begins to diverge in the first semester of the sophomore year. The diverging curriculum presents a challenge for the instructor, who must provide a valuable design experience to all engineering students. More importantly, though, it represents an opportunity for the student to learn the valuable lesson that they will often be called upon to be a team member (or leader) on a project in which they are not technical experts.

In the specific case of the can crusher design module, the mechanical and civil engineering students had all taken Statics and were concurrently enrolled in Solid Mechanics. The electrical engineering students had all taken Statics. The chemical engineering students had taken neither Statics nor Solid Mechanics. Although it may seem odd for ChE / EE students to be involved in the design of a can crusher, the clinic experience has proven that these students played a significant role in formulating engineering specifications, generating several concept designs, computer simulation, cost analysis, prototyping and writing the design report.

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