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Multidisciplinary Design and Communication: a Pedagogical Vision*

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The Sophomore Engineering Clinic I, which is the third course in an 8-semester design sequence taken by all Rowan University engineering students, serves the dual purpose of introducing students to formalized engineering design techniques and providing them with the necessary foundation for their careers as technical communicators. The course, required for all Rowan University engineering students, is team-taught by faculty from the College of Communication and the College of Engineering. The most effective way to bridge these two seemingly disparate topics begins with finding a common ground. The common ground in this case is quality. The underlying theme of Total Quality Management (TQM), already heavily stressed in the four 3-week engineering design modules, is also an ideal forum for evaluating and producing technical communication. One faculty member from each of the four engineering departments (Chemical, Civil, Electrical, and Mechanical) and two faculty members from the College of Communication work as a team to organize and plan the clinic. Preliminary results have shown that students experience increased confidence in both their technical and writing skills.

BACKGROUND

IN 1992, a local industrialist Henry M. Rowan made a $100 000 000 donation to the then Glassboro State College in order to establish a high-quality engineering school in southern New Jersey. This gift has enabled the university to create an innovative and forward-looking engineering program. Since 1996, the exceptional capabilities of each incoming class of approximately 100 engineering students at Rowan (avg. SAT score of 1260; avg. class rank of top 13%) have repeatedly verified the need for a quality undergraduate engineering school in the rapidly growing region of southern New Jersey. The College of Engineering at Rowan is comprised of four departments: Chemical; Civil; Electrical and Computer; and Mechanical. Each department has been designed to serve 25 to 30 students per year, resulting in 100 to 120 students per year in the College. The size of the College has been optimized such that it is large enough to provide specialization in separate and credible departments, yet small enough to permit 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 Clinics are 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, real-world design projects and research. The solutions of these problems require not only 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 a multidisciplinary team [1, 2]. Table 1 contains an overview of course content in the 8-semester engineering clinic sequence. As shown in the table, each clinic course has a specific theme although the underlying concept of engineering design pervades throughout. This paper focuses on the Sophomore Engineering Clinic I (the third of the 8-semester clinic sequence), which is team taught with the College of Communications and applies the principles of Total Quality Management (TQM) [3].

One hurdle that must be cleared to successfully implement the clinic vision is the need to seamlessly integrate engineering design and technical communication. In terms of engineering design, multidisciplinary student teams rely on the TQM approach to organize engineering specifications using the House of Quality system [4], develop several conceptual designs, evaluate these designs using Pugh's method and perform guided iteration to identify optimum designs.

The House of Quality is a design tool that has been developed to enable engineers and management to relate the attributes that a customer might associate with a quality product to the engineering characteristics responsible for such attributes. The House of Quality has become a useful tool

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

Year	Engineering Clinic Theme (Fall)	Engineering Clinic Theme (Spring)
Freshman	Engineering measuremnts	Competitive assessment laboratory
Sophomore	TQM with 3-week discipline-specific design modules	16-week multidisciplinary design projects
Junior	Product development	Process development
Senior	Year-long multidisciplinary	Design and research projects

for developing the engineering specifications for a product. Moreover, it provides a conceptual map that is useful for planning and communication amongst team members with various backgrounds. The graphical nature of the device enables team members with different backgrounds, problems and responsibilities to establish design priorities while referring to patterns of evidence on the house's grid [5].

A partially filled House of Quality developed for the can crusher problem is given in Fig. 1 [3]. The left side 'room' shows the Customer Attributes (CA's). These are the attributes as described in a

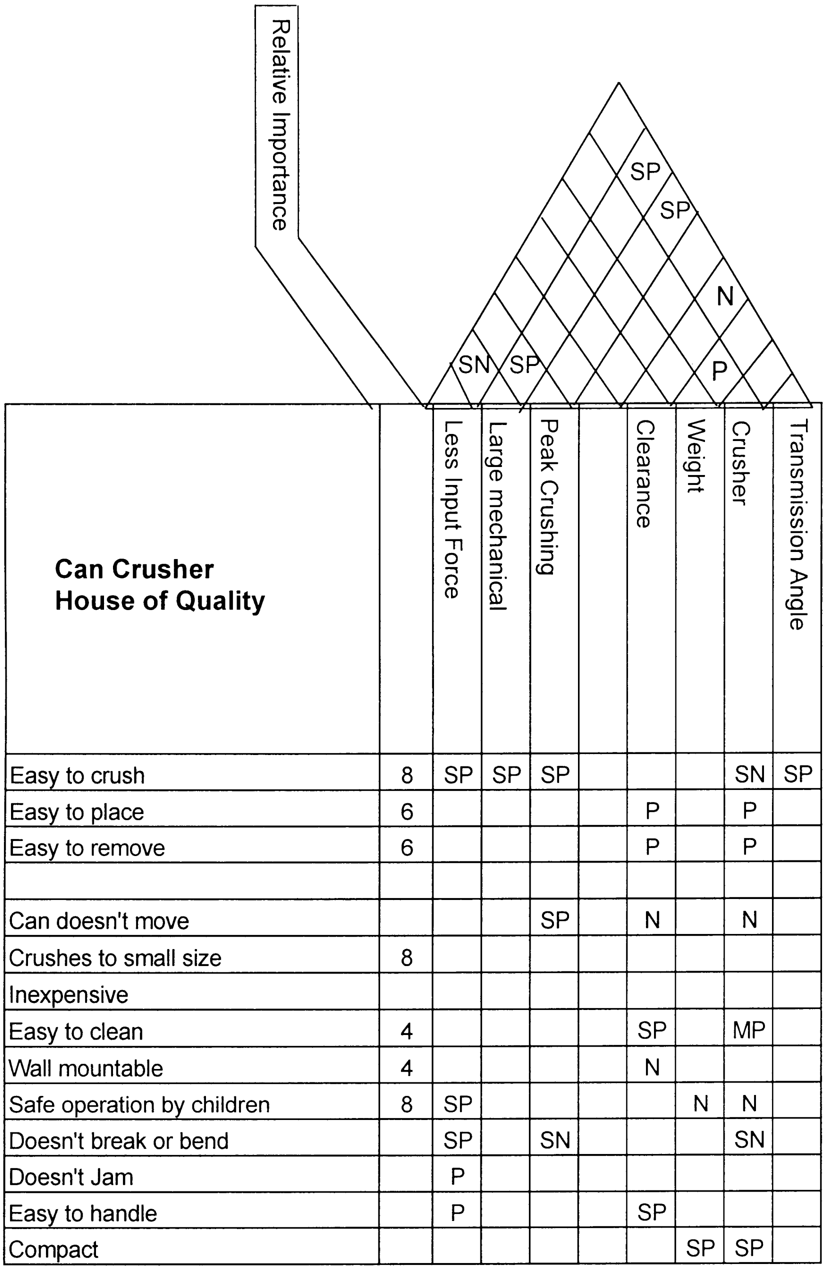


Fig. 1. The 'House of Quality' for a can crusher.

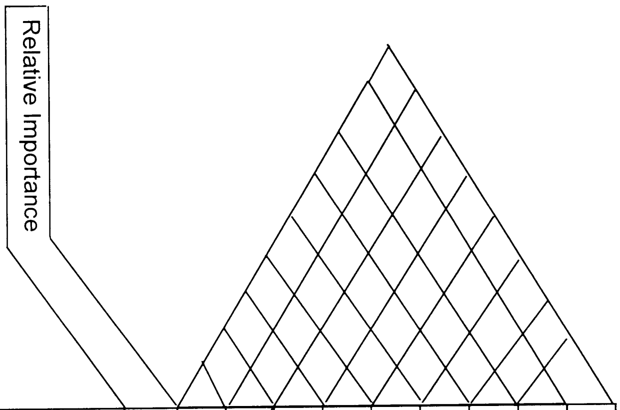
non-technical manner by the consumer, such as 'easy to crush, 'safe to use', etc.

As shown in the figure, these attributes are assigned a relative importance weighting from 0 to 10 based on consumer preferences. The top 'room' displays some of the technical parameters, popularly known as Engineering Characteristics (EC's). These are the technical characteristics of the device in engineering language, such as 'crushing force', 'weight', etc. The middle 'room' provides the relationships between customer voices and the technical characteristics. In this room, relationships between the CA's and EC's are labeled as:

- SP for strongly positive;
- P for positive;
- N for negative;
- SN for strongly negative.

This room not only provides very useful information in understanding the complex relationships among the CA and EC's, but also helps to identify any missing CA or EC. Another useful feature of the House of Quality is its ability to identify the conflicting requirements amongst the various EC's. In the attic, the labeling procedure outlined above is used to identify the trade-offs between the various EC's.

Engineers design systems with a particular customer in mind. Similarly, writers design documents with a particular audience in mind. Accordingly, we have found that the House of Quality is also an extremely useful tool for designing and evaluating technical documents. As shown in Fig. 2, the House of Quality can be used effectively to relate the attributes that a certain audiences might associate with a quality document to the rhetorical characteristics responsible for such attributes. In this case, a particular audience might list, 'easy to look at', 'friendly appearance', 'qualified



	Writing House of Quality	Relative Importance	Consistency	Sections, Headings	White space	highlighting	Background, Theory	Details	Method, procedure	Straight forward	Objectives, goals, focus
Easy to	Looks professional	8	P	SP	P	P	P	SP	P	P	P
	Find what you are looking for	8	SP	SP	P	SP		N	P	P	P
	Easy to look at	7	P	SP	SP	P		SN		P	
	Friendly appearance	6	P	P	SP	P		SN		P	
	Read efficiently	6	SP	SP	SP	SP	NN		P	P	P
Credible	Knowledgable	8	P	P	N	P	SP	SP	SP	P	SP
	Qualified	7	P	P		P	SP	SP	SP	P	SP
	Knows field, background	6	P	P		P	SP	SP	SP	P	SP
	No padding, kissing up	6	P	P	N	N	N	N	P	P	P
	Specific, Interesting	6	P	P	N	P	SP	SP	SP	P	P
	Purpose, value, benefit	8	P	P		N	P	P	SP	P	SP

Fig. 2. The 'House of Quality' for a writing assignment.

author', as attributes associated with a quality document. These audience attributes are then mapped into rhetorical characteristics such as 'white space' or 'headings'.

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; the civil engineering module focuses on design of a structure; the chemical engineering module focuses on design of a process; and the electrical engineering module focuses on design simulation.

We have found that the TQM approach is applicable to technical communication. For example, the House of Quality is a design tool that has been developed to enable engineers and management to relate the attributes that a customer might associate with a quality product to the engineering characteristics responsible for such attributes. This process is analogous to what occurs as a writer designs a document for a reader: writers must use particular document characteristics to realize and to shape the often unclearly stated expectations of readers, and they must evaluate the consequences and benefits of their design decisions. Importing an engineering design tool into the writing classroom does more than give engineering students a model for creating documents that meet their readers' needs, although this is certainly important. In many ways, 'borrowing a tool' integrates the writing and engineering emphases of this course at a deeper level. Students see that the writing and engineering faculty collaborate on the development of the curriculum. They draw on conceptual approaches that the rest of the engineering curriculum develops and realize that writing is an integral part of the design process. They learn that writing is an active and creative process rather than a static tool or artifact, and, as the House of Quality dramatizes, that it is a communicative and interactive process that engages writer and reader.

THE SOPHOMORE ENGINEERING CLINIC I

The focus of the Sophomore Engineering Clinic I is to involve multidisciplinary teams in four separate discipline-specific design modules. Each module demonstrates the principles inherent in the design of engineering systems: design of a product (mechanical), design of a process (chemical), design of a structure (civil), and design of a simulation (electrical). Communication is the common element linking these modules. To write a coherent report, the student must think clearly about the elements of the design problem. Student understanding of the technical material is enhanced though writing assignments within the modules [6, 7, 8]. When their writing courses are separated from their engineering courses, students tend to think that writing is an incidental or secondary tool that they will use minimally and always with great difficulty. Writing is often considered an obstacle, or at best, a necessary but unpleasant part of their work.

However, linking the writing course directly to a key engineering course creates a situation in which we can teach writing as a fundamental engineering practice and underscores the communicative and interactive nature of engineering. Specifically, writing serves three main purposes within the engineering curriculum. These functions are intertwined, not mutually exclusive, and may be described as:

- *writing to learn*—students describe, explain, analyze, and discuss information in order to understand it better. For example, students write an operations manual for the use of Kevlar and a set of application notes for a method of measuring temperature.
- *writing to communicate*—students analyze audiences (clients, peers, management, government, the public) and the situations in which documents are written and read and compose documents in order to meet needs within those conditions. For example, students write letters to the university president explaining their work with Kevlar, instructions to be used by parents or older children for assembling a child's tricycle, and technical descriptions of a spring-loaded scale for use in an inventory catalog.
- *writing to design*—students write documents that function as steps in the process of creating, constructing, testing, refining, and manufacturing a product.

The integration of the principles of quality, communication, and design represents a unique pedagogical vision. Quality is the encompassing concept spanning communication and design. Communication spans all aspects of design, and design itself can be caught in its components. This vision is shown schematically in Fig. 3.

THE FOUR MODULES

Design of a product—the can crusher

The 3-week design module sponsored by the Department of Mechanical Engineering introduces students to the production realization process with emphasis on design and development of a mechanism. 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.

Using principles from statics, each team designs

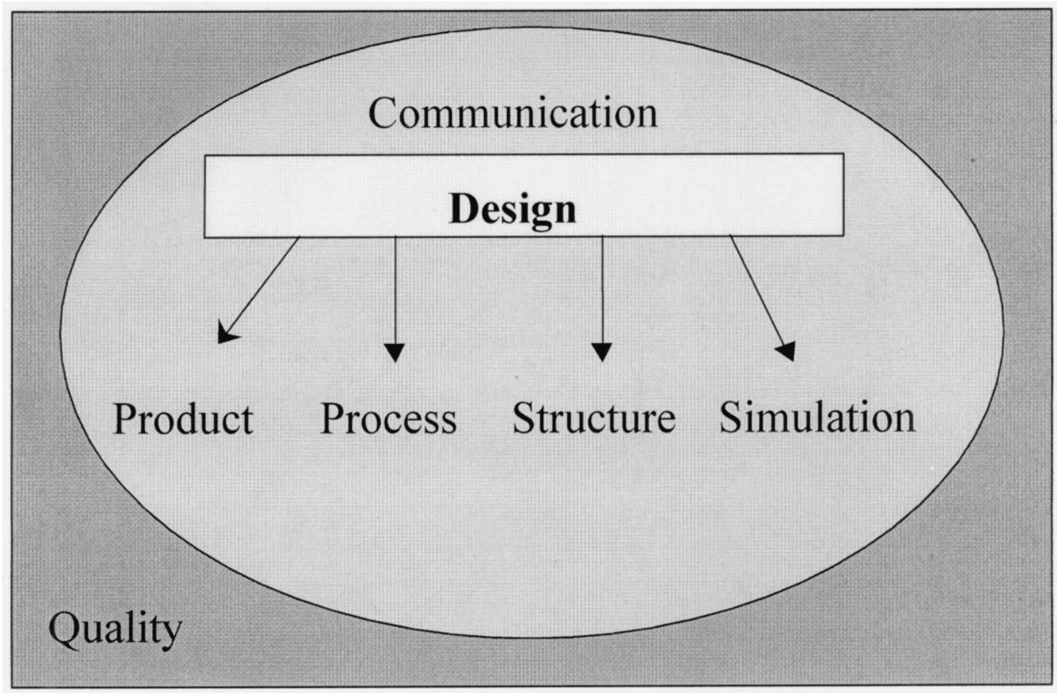


Fig. 3. Pedagogical vision of sophomore clinic.

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. 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 trial and error alone without going through the structured design process.

Design of a process—heat treatment of Kevlar

In this module, 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.

Next, 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.

Design of a structure—sheet pile wall

The three-week Civil Engineering module deals with 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 completing. The main objectives of the module are to:

a) use current technological tools to design a structure;
b) analyze a real-life problem using engineering principles;
c) evaluate the economics of design;
d) encourage cooperative learning;
e) 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 and maximizes individual 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. 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. 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. In addition, the students have to prepare a client report and present their solution to their peers and instructors.

Simulation/design—analog electrical filters

A three-week module stressing the simulation aspect of design is introduced in the form of a practical analog electrical filter design [9, 10]. 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 [11]. The existing equipment includes only a relative volume control which is not frequency selective. An equalizer filter that attenuates the dominant frequencies and boosts the suppressed frequencies to an acceptable level would be useful. 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:

(1) provide a structured introduction to a focused electrical design methodology for the purposes of solving a real-world problem;
(2) introduce simulation tools (*Pspice* and *MATLAB*) for verifying the design and computing a performance measure;
(3) introduce the student to electrical test/measurement equipment;
(4) 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 low-pass filter circuit is built and the frequency response measured. This is verified using *Pspice*. 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 cascade and/or parallel combination of low-pass and high-pass filters. The *Pspice* tool is used for software simulation and any design iterations are completed. During the third week, the equalizer circuit is implemented and the frequency response measured. To test the design and evaluate the performance, 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 are calculated as the performance measure. 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.

RESULTS

The sophomore clinic modules were used for the first time in the fall of 1998. In their course evaluations and an assessment survey of the clinic, students reported that their written and technical communication skills improved as a result of the modules. When asked to rank their ability to communicate effectively before and after taking this course, student self-ratings improved from 6.15 to 8.23 on a ten-point scale. Additionally, student comments included that it was beneficial that we covered a diverse area of engineering material and that the reports were integrated into the communications part of the course, requiring knowledge of both the module and critical technical writing. Of equal importance, the communication and engineering faculty found that the regular meetings and discussion facilitated the exchange of ideas that lead to increased integration of writing across the engineering curriculum and to improved use of technical examples in other communications courses.

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