Session 1265

Teaching Mathematics from an Applications Perspective

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Abstract

It is a widespread opinion and belief among engineering faculty that undergraduates enrolled in any engineering field could be better prepared in Mathematics when taking courses related to their professional field of study. The lack of preparation to apply appropriate concepts in Mathematics may be due to the fact that examples from engineering disciplines are not widely used in the Mathematics courses. It is typical of a Mathematics department to not only offer their degree programs but also act as a service department to students majoring in various fields. It is not economically justifiable for Mathematics departments to custom tailor courses in Mathematics for customers from different disciplines. On the other hand, engineering being a practitioners program, has a distinct requirement of creatively applying mathematical concepts and principles to engineering problems studied in various courses. Some of the issues related to inadequate preparation in application of Mathematics include: what type of mathematical background and level of mathematical competencies are needed in engineering courses; which Mathematics courses should cover such mathematical competencies; and what type of examples and problems related to students' major field should be developed and taught in Mathematics to enhance the understanding and application of mathematical concepts.

The primary goal of this research paper is to develop a conceptual framework for a Cross-curriculum Delivery system for engineering systems with the Department of Mathematics to deliver services effectively by co-operative efforts of customers and suppliers. Various quality tools are available which could be used in developing a framework for a Cross-curriculum Delivery system. This process requires the identification of customers' needs in terms of mathematical competencies required to teach core courses related to the manufacturing engineering students. The curriculum in Mathematics will be designed by the Department of Mathematics to meet students' needs. An on-going interaction between the customers and suppliers would promote the development of examples and real-life business and industrial problems to be used in the Mathematics courses offered to engineering students.

Introduction

Curriculum development is traditionally a product of isolated efforts of various departments at the University of St. Thomas. Consequently, the curricula in mathematics, science and engineering were not designed to accomplish optimal students' learning of their major fields of interest. The structure of the curriculum was based on engineering science which evolved after World War II (Grinter, 1955). In the current curriculum, the first two years consists mainly of courses in mathematics, science, communications and electives. Very few engineering courses are taken by the students in the first two years. A review of the literature reveals that integration of academic competencies in mathematics and other areas of science is not only possible but desirable (Sanders, 1989, 1992; Johnson, 1989; Reston, 1989). National, state, and local projects such as the Teaching Integrated Math and Science Project (Goldberg and Wagreich, 1989), the State Systemic Change Projects, and Technology, Science, Mathematics Integration Project (Sanders 1994) funded by the NSF are providing innovative instructional materials that integrate teaching in science, mathematics and technology.

It is widely recognized by engineering faculty that undergraduates in engineering programs should be better prepared in mathematics to successfully complete courses in their professional disciplines, etc.

Adequate use of engineering examples in the mathematics courses can enhance the familiarity of concepts in mathematics. Students majoring in various fields take courses in the mathematics department. Developing custom courses in mathematics for users from different disciplines may not be economically viable for mathematics department. However, learning various aspects of engineering relies heavily on creative application of mathematical concepts and principles to engineering problems. Among the issues related to inadequate preparation in being able to apply mathematics include: Identifying the type of mathematical background and level of mathematical competencies needed in courses offered in the department of engineering; matching mathematical competencies with the mathematics courses; developing examples of problems related to students' major field in various courses in mathematics to enhance the understanding and application of mathematical concepts; and so forth.

In order to accomplish the objective of learning mathematics from an application perspective, this paper develops a conceptual framework for a cross-curriculum delivery system for engineering students with the department of mathematics to deliver services effectively by co-operative efforts of customers and suppliers. The Quality Function Deployment (QFD) process is used in developing this system. This process requires the identification of customers'(students and the department of engineering) needs in terms of mathematical competencies required to teach core courses related to the manufacturing engineering students. The curriculum in mathematics would be designed by the department of mathematics to meet students' needs. An on-going interaction between the customers and suppliers would promote the development of examples and real-life business and industrial problems to be used in the mathematics courses offered to engineering students.

Quality Function Deployment

Quality Function Deployment (QFD) was developed in Japan in 1972. It is a highly structured format used to translate customer value requirements into specific product and service characteristics, and ultimately into the processes and systems that provide the valued products and services. The aim of QFD is to translate customer needs or wants into detailed technical requirements, and to set priorities using competitive data. QFD should help organizational processing activities and outputs match customer wants (Cole, 1989).

A typical QFD matrix is shown in Figure 1. On the left side of Figure 1 are the customer requirements: what the customer wants in the product or service. The top of the QFD matrix shows the manufacturer's or service provider's requirements, what the manufacturer or service provider does to ensure the consistency of the product or service. These can be items that are measured by the manufacturer or service provider and are specified from suppliers.

The right side of the QFD matrix indicates the planning matrix. This matrix specifies the level of services or product to be provided or produced after evaluating the customers' priorities and the competition. The QFD team selects the services or product attributes which have the greatest potential for success in the marketplace. This is achieved by assigning weights to product or service characteristics or attributes.

The peak of the QFD matrix represents the manufacturer's or service provider's requirements. This is where viable product or service attributes trade-off are identified. By identifying viable trade-off at an early stage, product or service development designers can narrow their development efforts, thus speeding up the development cycle.

The body of the QFD matrix translates customers' requirements into manufacturer's or service provider's terms. It is also where interactions among several interest groups are identified so that the synergistic effect is seen.

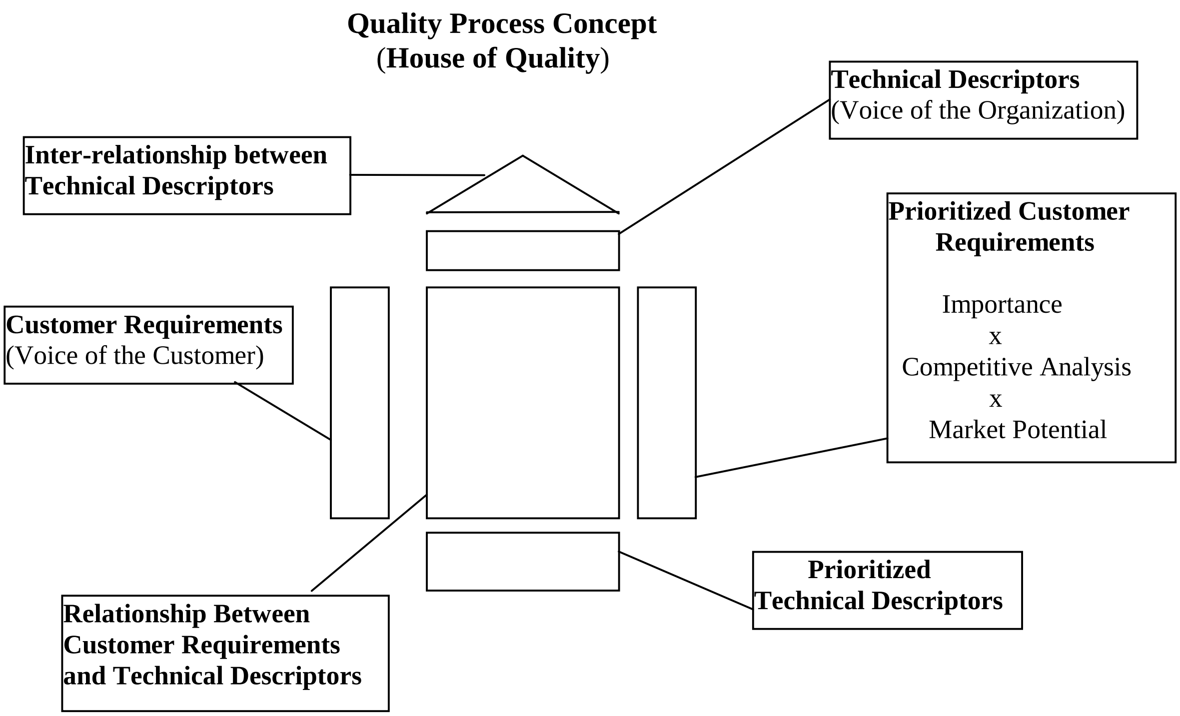

Figure 1: Structure of House of Quality: Component Matrices

The bottom of the QFD matrix is the prioritized manufacturer's or service provider's requirements. This identifies the requirements that are the most critical for success of the product or service. The degree of technical difficulty to achieve the goals is also indicated in this matrix.

As shown in Figure 1, QFD employs a "what-how" matrix listing customer wants (the "what"), technical requirements (the "how"), and competitive assessments using customers' subjective perceptions and the organization's own objective engineering measurements (King, 1989). Thus, QFD provides a way to integrate and subordinate specialized functions and departments into coordinated, collaborative activity that provides customer value. While many organizations will choose not to use such a structured technique, they will have to write operational definitions that clearly articulate the means of providing value to customers. These definitions will have to be translated into processes and operations to produce the products and services. QFD simply provides the structured methodology that promotes communication among the specialized experts who must do this work. There is more to QFD than simply filling out a "house of quality" matrix. It involves implementing a customer-oriented philosophy (Hauser and Clausing, 1988). The chief advantage of the QFD approach over other mechanisms is that it integrates, at a system level, different departmental activities through common task requirements. This minimizes deviation from customer wants throughout the product design and production cycle (Cole, 1989). Companies that use QFD can achieve a competitive advantage by delivering the products and services customers want. These outputs will be efficiently and effectively designed and delivered more quickly than those of competitors.

Implementing the QFD Process

As shown in Figure 2, the QFD house of quality is merely the first in a series of such matrices that translate the customers' needs into product and system requirements and specifications. The measures of customer needs and values are translated first into design attributes which are in turn the basis of product/service features. These required features are based directly on measures of customer needs. The features are then used to define the processes and operating conditions that are required to deliver value to the customer. Each step of the process in the house of quality, design matrix, operating matrix, and control matrix is based on clearly defined measures that incorporate customers' needs and values. The data produced in one stage of the development process are explicitly related to the decisions that must be made in the next stage.

The matrices centralize and make very visible and concise the data needed to generate product definition, design, production, and delivery decisions. The customers' requirements on the vertical dimension are individually matched with the design requirements on the top horizontal dimensions of the matrix. A coding scheme of circles, triangles, etc. is then used to indicate the degree and direction of influence of the most important requirements of the design. The matrices improve communication between team members, decision makers, and decision implementers (Griffin, 1992).

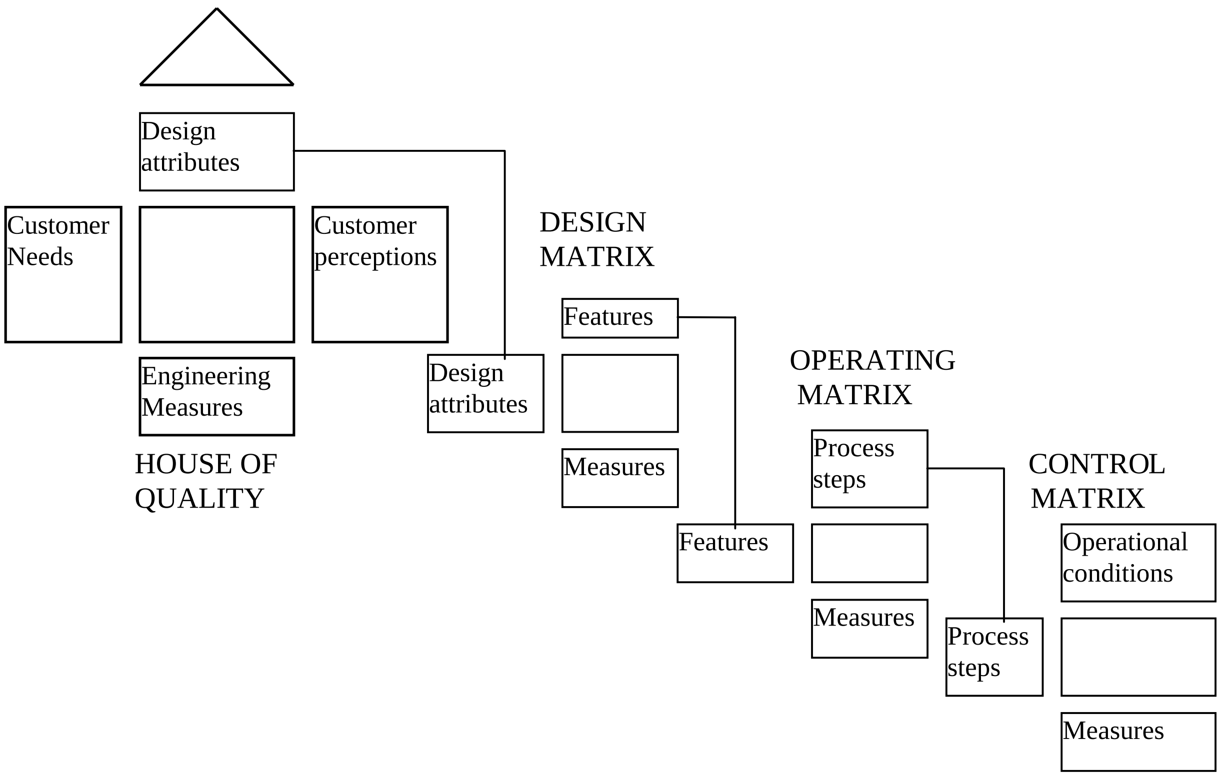

Figure 2: The flow of communications in translating customer needs into operations using QFD interaction matrices

The house of quality is the first step in negotiating what suppliers agree the design will achieve for customers. It defines those cost-effective design attributes that can be delivered to achieve customer perceptions of value. QFD has stages similar to the traditional US phase-review development process. However, with the simultaneous consideration of customer needs, engineering capabilities, and process design, QFD can contribute continuous cross-functional participation from start to finish and generates consensus decisions about trade-off (Griffin, 1992). The QFD process helps team members from each department to: understand what the external customer values, and understand their contribution to the systems and processes that provide the value. This understanding provides a basis for cross-functional teamwork and collaboration.

A recent example of an integration effort relates to Northwestern University's efforts in developing new core curriculum called "Engineering First" which integrates a subset of mathematics and science with engineering (Belytschko, et al, 1997). They have chosen linear algebra and differential equations as the courses for integration as these courses closely relate mathematics to the computer solution of engineering problems. The examples cover science of mechanics, circuits and communication networks in these courses. The analytical topics are covered in a four course sequence taught in a pilot version called Engineering Analysis, which begins with the first quarter of the freshman year. The familiarization of students with computer methods in these courses enable introduction of design analysis to students. They have also developed a program of evaluation, and they report that early results are quite favorable.

The two QFD matrices will form the framework of cross-curriculum delivery system for engineering students. The first matrix will link customer requirements with the design features (attributes) of service. The second will relate the design features (attributes) of service with the operational features of service delivery. The QFD analysis involved in developing the two matrices include: determining priority ratings of customer requirements; doing competitive analysis of customer requirements; determining weighted priority of design features (attributes) of service and weighted priority of operational features of service delivery; and doing benchmark comparisons of design features of service and operational features of service delivery; besides doing trade-off analysis of design features of service and operational features of service delivery.

Taking again the Northwestern's "Engineering First" curriculum with Linear Algebra course as an example; the <u>customer requirements</u> associated with learning Linear Algebra may include: Learn basic Linear Algebra of square and rectangular systems (for instance, matrix notation, solution of square systems using the LU decomposition, matrix inverses, rectangular systems, subspaces, spanning sets, linear independence and dependence, dimension and rank, projections and least squares, etc.); Learn computational aspect of linear algebra (for instance, concept of computer arithmetic; basics of MATLAB- scalars, vectors, matrices; arithmetic operations in MATLAB; basic MATLAB functions; linear algebra concepts (such as, matrix products, dot products, transposes); decision and loop structures; modularization (in MATLAB through M-files), and so forth.

The <u>design features of service</u> to teach Linear Algebra may include: Theory of Linear Algebra (such as, matrix and vector notation and operations and recognize equivalence between systems of equations and matrix notation; singular and non-singular systems; the mathematics underlying row operations; the ideas behind the LU decomposition and the importance of this decomposition in solving systems of linear equations; the concepts of inverses; the differences between rectangular and square systems; the concept of vector space and subspaces; and so forth); Programming aspect of the course (such as, decision and repetition structures showing applications of these structures;
importance of modularization for the program development and debugging; generation of graphs and plots in 1 and 2 dimensions showing interpretation of the results of computations through graphics; working through programming projects in computational linear algebra; and so forth).

By ranking customer requirements, and also assigning the level of co-relationship between customer requirements and design features of service, the first QFD matrix is developed by computing other needed data to complete the matrix. The second QFD matrix relates to the implementation and evaluation of the curriculum-delivery system. The implementation deals with how well the teaching of the new curriculum was organized. The evaluation deals with student satisfaction, their perceptions of course difficulty, and workload, how the new curriculum meets the student's perceived needs, and so forth. The first QFD matrix is the same as the House of Quality matrix shown in Figure 2. The second QFD matrix combines the features of the third and the fourth matrices - operating matrix and control matrix in Figure 2. The second matrix called Design matrix in Figure 2 is not relevant as we are dealing with service product as opposed to manufactured product.

Conclusion

This paper provides only the conceptual framework of cross-curriculum delivery system. In order to develop the detailed system, inter-disciplinary team of instructors from Math, Science, Computer Science and Engineering along with a group of engineering students undergoing the new integrated curriculum will have to be formed. This new system has merit in view of the fact that while the workplace has changed significantly, engineering education has not changed for the past three decades. Increasing emphasis of ABET and employers on design and computational ability of engineering students warrants better prepared students in the engineering skills in order to be a productive members of the technical workforce.

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Biography

Sameer Kumar is a Professor in programs in Manufacturing Systems and Engineering at the University of St. Thomas. Prior to joining St. Thomas, he was a Professor of Industrial Engineering at the University of Wisconsin-Stout. He has worked in industry in various positions including research, engineering, manufacturing and information systems. He holds PE license, and CMfgE, CMfgT, and CPE certifications and has a Ph.D. in Industrial Engineering from the University of Minnesota. He also has Master's degrees in Mathematics, Computer Science and Industrial Engineering and Operations Research. Dr. Kumar has published a number of articles in various professional academic journals.

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