Advances in Engineering Education

Infusion of Emerging Technologies and New Teaching Methods into The Mechanical Engineering Curriculum at The City College of New York

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ABSTRACT

From October 2003 to April 2008 a systemic reform of the Mechanical Engineering program at The City College of New York was undertaken with the goal of incorporating emerging technologies (such as nanotechnology, biotechnology, Micro-Electro-Mechanical Systems (MEMS), intelligent systems) and new teaching methodologies (such as project based learning, hands-on laboratory experiences, inquiry based learning, home experiments) into the curriculum. This reform activity was supported by NSF and affected all the courses taught by the Department. Almost all faculty participated in the effort. In this paper, we describe the modifications introduced in four courses of the curriculum, namely, Mechatronics, Mechanics of Materials, Heat Transfer and System Modeling, Analysis and Control. The modifications consisted both of topics related to emerging technologies and new teaching methodologies. Results of assessment conducted to ascertain the effect of the changes are presented. For example student opinions about course outcomes before and after the modifications were surveyed for the four courses discussed above. Based on the limited assessment data available thus far, it appears that students' confidence and overall academic performance has improved in some courses following the reform. It is the authors' opinion that these will see further improvement in coming years as the specifics of the reform elements are refined.

Key words: curriculum reform, emerging technologies, teaching methodology

INTRODUCTION

The Mechanical Engineering Department, as many departments in the country, is engaged in a continuing effort to review and upgrade its curriculum. The impetus for this has always been the ever-changing nature of the profession. However, in recent years a confluence of circumstances has accelerated these changes, requiring urgent and comprehensive curriculum reform. There are two distinct currents that are driving ME programs to reform their curricula.

First, is the emergence of new technologies that are revolutionizing the practice of engineering. The miniaturization of mechanical devices, the advent of nanotechnology, the advances in information technologies, the emergence of intelligent systems, the introduction of new and advanced materials, the development of sophisticated software and finally the revolution in biology cannot be ignored in designing a modern mechanical engineering curriculum. Nationally, with respect to its technical content, mechanical engineering education today is at a juncture not unlike the watershed that ended in the publication in 1955 of the Grinter Report [1]. As a result of this report, the engineering sciences portions of engineering curricula were strengthened and their core content defined. It is interesting to note that in spite of revolutionary advances in technology, the core courses recommended by the Grinter Report closely resemble the typical mechanical engineering core curriculum today:

Mechanics of solids (statics, dynamics and strength of materials)

Fluid mechanics

Thermodynamics

Transfer and rate mechanisms (heat, mass and momentum transfer)

Electrical theory (fields, circuits and electronics)

Nature and properties of materials (relating particle and aggregate structure to properties)

As in most ME departments, until recently, the undergraduate engineering science curricular component of the CCNY department of Mechanical Engineering largely followed this traditional pattern and was in need of reform. Recent developments in the department had kept pace with the ME academic mainstream through reduction of overall credits required, more extensive use of computational methods and a new required course in mechatronics. However, these changes still placed us far from the cutting edge of technology. One indication of this problem was that students in senior design courses were often uncomfortable with design projects sponsored by our research laboratories or by industry when they departed from the traditional mechanical engineering knowledge base and involved emerging technologies.

The second current compelling reform is the new trend in pedagogy that is gaining currency among science and engineering educators. According to this reform movement, engineering education must take into consideration industry needs, must be based on cognitive science, and should promote technological literacy.

The 2004 National Academy of Engineering Report: *The Engineer of 2020* [2] urges engineering educators and curriculum developers to adapt their programs to address the complex technical, social, and ethical questions raised by emerging technologies. The report expects engineering schools to attract the best and brightest students and provide innovative and all-around training so that they can tackle modern-day issues, which result from the complex technical, social, and ethical questions raised by emerging technologies, such as nanotechnology, information technology, and bioengineering, etc.

During the past decade, a growing body of literature has been published to report on how people learn based on cognitive science. For instance, the quintessential report edited by Bransford et al., 1999 for the National Research Council [3] correlates the functions of an individual's brain and mind in learning through daily experience and schooling. The report provides the pedagogical foundation for understanding how a student acquires knowledge through motivation, cognitive dissonance and conceptual change. Such increased understanding of teaching and learning paves the theoretical framework for the curriculum reform and development in this study.

As reviewed recently by Trundle et al., 2010 [4], this is even more apparent when adopting simulation and modeling tools in teaching to refine pedagogy. Since PC's became cost-effective and available decades ago, simulation and modeling tools (including multimedia) have been widely adopted in engineering training because of their effectiveness in helping the understanding of the subject by giving the possibility of experimenting with various scenarios (van Rosmalen and Hensgens, 1995 [5]; Kassim and Cadbury, 1996 [6]; Carter, 2002 [7]). In particular, the use of simulation and modeling as learning and instruction tools have been used in teaching subjects relevant to system dynamics, such as control engineering (Kheir et al., 1996 [8]), mechatronics (Ume and Timmerman, 1995 [9]), chemical process control (Perkins, 2002 [10]; Cox et al., 2006 [11]), and manufacturing (Ong and Mannan, 2004 [12]).

Due to the easy availability of network communications, both wired and wireless, as well as the societal needs for distance learning, recently the 2008 National Science Foundation (NSF) Report: *Fostering Learning in the Networked World* [13] presents the opportunities and discusses the challenges faced by cyberlearning. A good number of investigations had been devoted to studying the effectiveness of web-based remote learning, especially those related to laboratory and design issues (Allen, 1998 [14]; Granlund et al., 2000 [15]; Ong and Mannan, 2004 [12]; Nickerson et al., 2007 [16]; Selmer et al., 2007 [17]). As identified in the 2008 NSF report, cyberlearning, especially those using multimedia simulation and modeling help cross-disciplinary teaching and learning. It allows the educators to instill more easily a platform for the sharing and inter-operating of hardware, software and services. Because of the transformative power of information and communications technology, such open educational resources will provide easy access for life-long learning.

Based on the context provided in the foregoing, the main objective of the effort was to undertake a systemic reform of the CCNY Mechanical Engineering program with the following thrusts:

a. incorporation of emerging technologies such as MEMS/NEMS, nanotechnology, biotechnology, intelligent systems/electronics, advanced materials, computer aided engineering (CAE) and nontraditional energy into the curriculum, and
b. introduction of new teaching strategies focused on student learning such as project based learning hands-on laboratory experiences, inquiry based learning and home experiments.

Home experiments are very simple experiments designed to enable students to perform them at home without the need for special equipment or instruments. Students use crude measurements to experimentally determine factors such as heat transfer coefficient and cooling time. As an example, students are asked to heat a hanger wire to a specified temperature in an oven, suspend it horizontally in still air, calculate the time needed to cool the wire to body temperature and use the lumped capacity method to estimate the heat transfer coefficient. The estimated value is then compared with theoretical prediction using free convection correlation equations.

Over a three year period all the courses offered by the department were modified to incorporate emerging technologies where appropriate and/or new teaching strategies. During the following year implementation was completed and some assessment conducted.

At the time of implementation the Mechanical Engineering department at the City College had 17 full time faculty members, 16 of whom participated in the reform effort. Since its completion, the reformed curriculum affects approximately 350 mechanical engineering majors yearly. The NSF grant enabled the department to introduce new equipment and software in the labs and provided funding for faculty participation. Converting the student laboratory experience to hands-on mode has been expensive, since it requires the hiring of additional laboratory assistants to assist the students. So far the additional software expenditures have been incorporated into the department's budget and the Dean has provided additional funds for the laboratory assistants. Programs contemplating similar improvements in their curriculum should be prepared for additional expenditures. We believe that many aspects of the reform efforts, especially the introduction of a stand-alone Micro/Nano Technology course and the broadening of the science offering, can be easily adopted by other ME programs. Also, we are cognizant of the fact that many ME programs are undertaking similar efforts to introduce emerging technologies and new teaching methodologies into their curricula, and could benefit from our experiences as descried in this paper.

DESCRIPTION OF REFORM

Even though each course has been modified using the two guiding principles (i.e, incorporation of emerging technologies and introduction of new teaching methods), the actual application has been tailored to the nature of the course. For example in ME 41100 (System Modeling, Analysis and Control) to accomplish the objectives of the course only new teaching strategies emphasizing: (1) collaborative learning by student teams for problem solving, (2) just-in-time integral learning using analytical, computational and experimental approaches, (3) close linkage between mathematics skills and engineering applications, (4) student-initiated knowledge exploration, including exposure to emerging technologies, were adapted. In short, the course reform placed learning in students' own hands. For Mechatronics (ME 31100) the traditional homework and conventional laboratory experiments were supplemented with "labwork" assignments. To solve these "labwork" assignments, students were required to work as a team in the laboratory outside class hours. Each team was assigned several engineering problems to be solved (e.g., to find the stress concentration factor of a rectangular plastic plate with a U-notch under uniaxial tension). Instead of conventional approach (e.g., finite element method), the team was asked to use the equipment and software available for them in the lab (e.g., three strain gages and a strain indicator); design, set-up and conduct their own experiment (e.g., where to place the three strain gages at the most suitable locations so that the stress concentration can be assessed most accurately); analyze the data and compare their results with solutions obtained by other means (e.g., from textbooks/handbooks, finite element solutions, etc.); and finally submit final written reports. In ME 43300, Heat Transfer, the emphasis was on the addition of new materials related to emerging technologies, namely, heat transfer in living tissues and microchannels. Addition of the new material required eliminating and abridging some topics while preserving the fundamentals of conduction, convection and radiation. Based on many years of teaching the course, the instructor decided to: (1) Eliminate a chapter on two-dimensional conduction, the derivation of Blasius and Pohlhausen solutions, and radiation in three-surface and multi-surface enclosures and (2) Abridge a chapter on convection correlation equations. It is worth noting that this abridgment proved to be an effective pedagogical approach to correlation equations. Instead of presenting and discussing individual equations, students were taught a systematic procedure for selecting an appropriate equation for a specific application. On the other hand in ME 33000, Mechanics of Materials (MoM), in addition to introduction of emerging technologies, home experiments also were introduced. Course content was modified to include residual stresses (which are a pervasive issue in very large scale integrated circuits), thermal stresses in composite rods, thin films, solder joints in printing circuits and bi-metallic strips. Also, several examples of beams in MEMS were analyzed and illustrated. Besides content update, four simple home experiments were added to enhance the understanding of basic concepts.

All the courses in the Mechanical Engineering program taught by the department were first analyzed and then modified as needed, in the fashion described above. Cognizant of the fact that the material related to emerging technologies may require additional science background, the list of science courses available to our students was expanded to include additional courses in biology, chemistry and physics. Since students choose two courses from the list, the expansion of the science electives list did not lead to an increase in the number of required credits. Finally, to give students a more comprehensive view of manufacturing at small scales, a required Micro/Nano Technology course was added to the curriculum. To keep the number of required credits constant, the previously required "Power Plants" course was made an elective.

EXAMPLE APPLICATIONS

To describe the reform effort in more detail, below we discuss the modification of four specific courses, namely, Mechatronics, Mechanics of Materials, Heat Transfer and System Modeling, Analysis and Control.

Mechanics of Materials

Mechanics of Materials (MoM) is the first course in solid mechanics, which covers stress, deformation and strength of simple shaped members, and their applications. Topics include concepts of stress and strain, uniaxial loading, torsion, beam bending, column buckling and stress/strain transformation, etc. As a mandatory course, it has far reaching effects on students' future learning and career development.

Since the introduction of Timoshenko's book [18], *Strength of Materials*, the subject has become so well defined that the content and coverage of the course have been almost fixed for many decades. On the other hand, due to the advancement of technology, MoM has found many new applications. Mechanical engineering students are having more and more employment opportunities in emerging technologies other than conventional industries such as automobile companies. There is a need to expose students to many real life applications of MoM especially in emerging technologies.

The work reported here is part of the department's effort in incorporating emerging technologies into the undergraduate curriculum.

One of the difficulties is the limited instruction time. As a one-semester fundamental course, all the existing topics covered are deemed indispensable. Therefore, the basic principle of the reform was to keep all the basic topics intact while replacing many old examples by new ones from real life and emerging technologies. These new examples were used to illustrate basic concepts, to give a broad view on the applications of the course, especially in modern technologies, to make the course more interesting, to provide working knowledge in emerging technologies and more importantly to cultivate the ability of modeling, formulating and solving real world engineering problems.

Based on these considerations, more examples from the real world were added, the course content was expanded to include thermal stresses as a special topic, home experiments were assigned, and several applications of beams in MEMS were introduced. Besides content, some changes were also made in the teaching methods.

Using Real World Examples to Learn the Modeling Process

Traditional textbooks on Mechanics of Materials, such as the one by Beer et al. [19] usually have excellent homework problems and examples. For example, a straight bar and some simple symbols at its ends represent a beam under certain loading conditions. The advantage of these problems is that the student can directly apply the newly learned concepts or techniques without being distracted by other factors, which could be important but do not directly relate to the key concepts focused on at the time. However, if all the problems were presented in this fashion, in their minds, students might gradually start to think of a beam as what we draw on paper and may not realize or identify that ski boards under a skier's feet are also beams, or that a person standing on a ladder is a beam problem etc. Some MoM textbooks, such as the one by Hibbeler, [20] have many examples presented as they are in the real world. Many of these problems were adopted in this course either as examples or as homework problems. Our purpose is not simply to solve these mechanics problems, but to teach explicitly the process of modeling, formulating and solving a real problem.

Many practical applications were included as sample problems in class and also in homework, such as the stress analysis of a water tube, a nut and a wrench when the wrench is tightening the nut on the water tube, of a traffic light pole, of pliers, and of a helicopter propeller shaft, etc. Through modeling practice, students are exposed to the applications of theory in the real world, and most importantly, they learn how to make reasonable assumptions to simplify a problem, solve it, and design for strength.

Enhancement of Thermal Stress Instruction

The structures in modern technologies are usually made of different materials. For example, any Very Large Scale Integrated (VLSI) structure has metal conductor, semiconductor and glass insulator. For such composite structures, thermal stress is a pervasive issue due to temperature difference between the on/off states of power and during the manufacturing process. In the past, thermal stresses were only briefly mentioned after uniaxial loading was introduced. To help students realize and understand many mechanical problems in emerging technologies, we feel that there is a need to enhance the content of thermal stress instruction in the course.

Besides the existing examples of thermal stresses in a rod with fixed ends and in a composite cylindrical bar, more examples such as thermal stresses and fatigue of solder joints in the flip chip technology (Figure 1a), and thermal stresses in thin films (Figure 1b) were added. For the problem in Figure 1a, the worst scenario, a solder ball under one edge of the chip is considered. If the temperature changes by ΔT from the stress-free bonding temperature, the horizontal displacement difference between the top and bottom surfaces of the solder ball is about $\Delta\alpha\Delta TL/2$, where $\Delta\alpha$ is the difference in coefficient of thermal expansion (CTE) between the substrate and the chip and L is the width of the chip. If the height of the solder ball is h, then the shear strain at the solder ball is about $\Delta\alpha\Delta T\ L/(2\ h)$. Then the problem becomes a typical one which is solved when the concept of stress is introduced at the beginning of the course. For the thin film problem, since the substrate is much thicker than the film we assume that the stresses in the substrate are negligible and the in-plane deformation of the film is the same as that of the substrate, which is dominated by thermal strain. Therefore, the stress in the thin film can be calculated using two-dimensional stress-strain relations. The validity of the assumption is verified and the bending curvature of a thin film strip is obtained after we treat the thin film strip as a limiting case of a bi-material strip (Figure 1c). By replacing Young's modulus E in the bending curvature by $E\ (1-\ \nu)$, where ν is the Poisson's ratio, we obtain the widely used famous Stoney equation for wafer bending curvature (Figure 1b). Though we don't give rigorous proof which usually involves plate bending, we explain the replacement by comparing the stress-strain relations for uniaxial loading and equibiaxial loading. Then the significance and application of Stoney equation in determining residual stresses in thin films in the semiconductor industry is discussed.

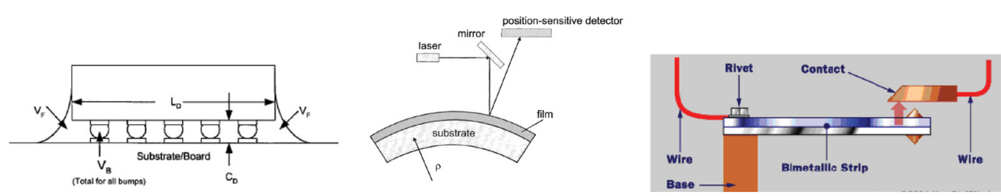

Figure 1. a) Solder joints in flip-chip technology [21]; b) Wafer bending due to residual stress; [22] and c) Bi-metallic strip as switch or temperature sensor. [23]

After pure bending is introduced, bending due to temperature gradient in the thickness direction of a homogeneous strip, and the bending of a bi-metallic strip can be taught. These two are excellent examples of integrating learned materials and using linear superposition technique to solve more complicated problems. For example, the strip bending due to temperature gradient can be treated as follows: we first solve the thermal stress in the strip, assuming the two ends are fixed and the beam remains straight. To satisfy the free end condition in the original problem, we add reverse tractions at the two ends, which could be approximated by a resultant force and a moment. The problem of bending in a bi-metallic strip due to the mismatch in the coefficients of thermal expansion could be treated the same way: calculating the thermal stress for the fixed ends case plus uniaxial loading and bending of beams made of different materials. Using linear superposition technique, students would find that each sub-problem had been solved previously. Due to the wide application of the bi-metallic strip as thermometer or actuator in temperature control, it is a very interesting topic for students to explore.

Applications of Beams in MEMS

Many MEMS structures are beams. Understanding the working mechanisms of MEMS usually require the knowledge of electrodynamics, but some MEMS are pure mechanical devices and can be directly analyzed using the knowledge of beam bending. The examples include the probe of Atomic Force Microscope (AFM) for detecting adhesion force and surface profile, [24] beams for measuring elastic constants at small scale etc., [25] and a bio-functionalized cantilever beam as a sensor for detecting molecules of biological interest [26] (Figure 2). The bending of AFM probe (Figure 2a) due to vertical adhesion force is a typical problem of a cantilever beam under concentrated force at the end. The force can be determined by measuring the slope at the end of the beam, so can the deflection, which is related to surface profile. The modeling and formulation for the problem in Figure 2b is the same as in Figure 2a, but for a different application, to determine the Young's modulus of the beam by measuring the deflection of the beam and the force applied. For the problem in Figure 2c, we first introduce the concept of surface tension, and explain that one side is coated with a layer of molecules which have a specific functional group to adsorb certain anti-body molecules in the environment, and the surface tension at the surface can be changed by coating and further by adsorption of the anti-body molecules. We can imagine the problem as two stretched rubber bands, with different tensions, bonded to the top and bottom surfaces of the beam. The problem can be modeled as a beam subjected to a uniaxial load and a moment, $tb\Delta\gamma/2$, at the end, where $\Delta\gamma$ is the difference of surface tension between the top and bottom surfaces, t

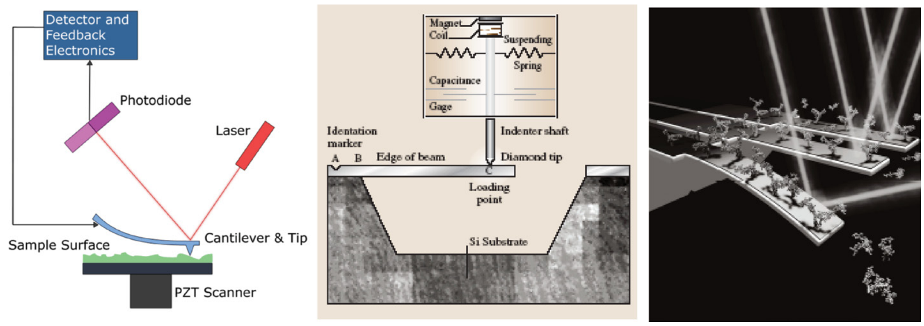

Figure 2. Some examples of application of beams in MEMS. a) AFM probe [24]; b) beam for measuring elastic constants at small scale; [25] and c) A biosensor for detecting anti body [26].

is the thickness of the beam and *b* the width. The change in slope at the end is derived as a function of the bending moment. Therefore, by monitoring the change of the slope at the end, the beam can be used as a sensor for detecting adsorption of antibodies.

The beam structure and loading conditions are simple in the above applications, but through these examples, students are exposed to applications at small scale.

Mechatronics

Mechatronics, a truly multi-disciplinary approach to engineering, integrates the classical fields of mechanical engineering, electrical engineering, computer engineering, and information technology to establish basic principles for a contemporary engineering design methodology [27]. Mechatronics has become a key to many different products and processes. Modern systems have reached a level of sophistication which would have been hard to imagine using traditional methods. The integration of mechanics, electronics, control and computing exploits and exceeds the relative advantages of each discipline, and when they are integrated, the synergy ensures that performances reach unprecedented levels [28]. The importance of Mechatronics Engineering will further increase due to consumer demands. Thus it has a vital role to play in the new millennium.

The global engineering market requires engineers who embrace mechatronics perspectives with advanced systems skills for participation on multi-disciplinary teams [29, 30]. There has also been significant activity in the last decade to revise engineering curricula to include more concrete engineering practice rather than just engineering science [31]. In this respect a key strength of the ME 31100, Fundamentals of Mechatronics course at City College of New York is the laboratory which encourages students to apply and absorb mechatronics concepts. The main goal of the laboratory is to help students gain useful knowledge and skills in the general area of sensors and actuators, ordinary differential equations used to model measurement systems, laboratory software and signal conditioning [32]. Such knowledge and skills are necessary for the success in students' future professional careers (including graduate studies) and for the continuation of their life-long learning. In order to achieve this goal, students complete several laboratory experiments. The experiments start with a short tutorial explained by the instructor and the students working in teams conduct the experiments based on this tutorial while being closely monitored by the instructor or lab technician. In this way the students achieve confidence using their practical and experimental skills. A novel concept regarding the laboratory experiments was introduced in order to develop abilities for the students to identify and formulate real-world engineering problems, carry out research, think creatively and work individually. In this respect, in addition to the experiments conducted in the classical manner the students receive "labwork". For this novel type of homework assignments the students work independently in the laboratory outside class hours. In order to solve the labwork they use the laboratory equipment and software and follow the experiment information detailed in the homework description. The students are able to independently solve the labwork without the instructor's help and communicate the results through written reports. The labwork include engineering concepts the students learned during the theoretical part of the course and require students to use their skills concerning laboratory software and equipment and engineering problem solving. As a result the students are challenged to independently solve and analyze an engineering project and gain confidence in their ability to apply their knowledge to new and unexpected situations. The labwork experiments expose the students to practical and theoretical issues and are described below.

Labwork experiment descriptions

The labwork covers topics introduced in the mechatronics course ME 31100 and also in the mechatronics laboratory experiments. The laboratory experiments feature the integration of sensors, actuators and real time data acquisition and control using industrial hardware and the software LabView and MatLab [33, 34]. The laboratory experiments cover the information presented in the mechatronics course and include; stress and strain measurements using strain gages connected in a Wheatstone bridge configuration, monitoring the speed of several bodies during free fall using optoelectronic sensors, study of mechanical vibration using four transducers, piezoelectric accelerometer, capacitive transducer, velocity transducer and linear variable differential transformer (LVDT), and temperature measurements using thermocouples.

Each of these experiments is intended to have the following activities [35]:

- Understanding the problem, identification of objectives and variables to be controlled.
- Understanding the physical principles of the sensors and the process to be controlled

- Selection of the appropriate control algorithm and nature of the interface
- Connecting the system
- Development and implementation of the computer program in LabView and MatLab.

The labwork has the same scope and activities as the experiments. The students are allowed to work in groups and they are in the laboratory when no classes are scheduled there. The difference between the laboratory experiments and labwork consists in the fact that students do not receive help from the instructor when they are working for labwork. In this way the students are required to think independently and gain confidence in their skills and knowledge. These labwork assignments were created in order to introduce in practice the theoretical concepts developed in the mechatronics course. During the semester the students are assigned four labwork assignments, which are described below.

Labwork about the stress and strain concentrators

The objective of this labwork is to demonstrate the existence of stress (strain) concentration in the vicinity of a geometric discontinuity created in a polymethyl-methacrylate (PMMA) bar. It is intended to familiarize students with the strain gage concept and the procedure to mount and bond Vishay strain gages [36].

For this labwork ten PMMA bars with different discontinuities were prepared as illustrated in Figure 3. The discontinuities are simple circular or semicircular holes, notches and cracks, drilled through the depth of the bars, in the center or at the edges of the bars. The PMMA bar containing the discontinuity is loaded by a uniaxial tensile force, as shown in Figure 4. In the cross section containing the discontinuity the stress is not uniform. The stress has a maximum value at the edge of the hole and decreases rapidly with the distance from the hole. The ratio of the maximum strain to the nominal strain at section B, Figure 4, is the strain concentration K_ϵ due to the disruptive presence of the hole.

In order to measure the stress value around a discontinuity the students are asked to mount 3 strain gages in the vicinity of the hole at varying distance from the edge of the hole, with one of the gages placed adjacent to the edge. In the Mechatronics laboratory a special kit for bonding the strain gages is prepared for this labwork. The kit contains additives, bonding pens and materials needed for the bonding of Vishay strain gages along with a description of the bonding procedure. Using the labwork description, the special kit and the bonding information the students are able to mount the Vishay strain gages on the PMMA bars without any help from the instructor. They also make the decision about the area where they will glue the strain gages on the specimen. A P-3 Wheatstone-bridge strain indicator is used to measure the strain. Based on the strains indicated by the three strain gages the students draw the stress and strain diagram around the discontinuity for the specific PMMA bar and calculate the stress (strain) concentration factor.

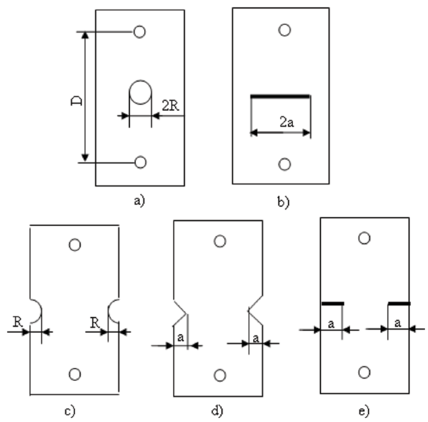

Figure 3. Various PMMA plates with discontinuities.

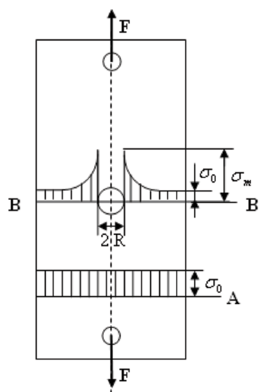

Figure 4. PMMA bar with discontinuity (hole). The stress diagram in the vicinity of the hole is explained.

Labwork about recording the frequency of the tuning forks

During this labwork students get familiar with sound collection using a PC sound card and a microphone. The sound is produced by a set of tuning forks. The tuning fork vibrations create pressure variations. The pressure variations are recorded using a microphone. The resulting signal is transferred to the PC using a sound card. The students are asked to write Matlab programs in order to acquire and analyze frequency data. The set-up for this labwork is illustrated in Figure 5.

Eight different tuning forks are used for this labwork along with an acoustic box, which is used as support for the tuning forks. The students are asked to vibrate each tuning fork separately hitting them with a rubber tuning fork hammer. A Matlab program is used to acquire data which consist of

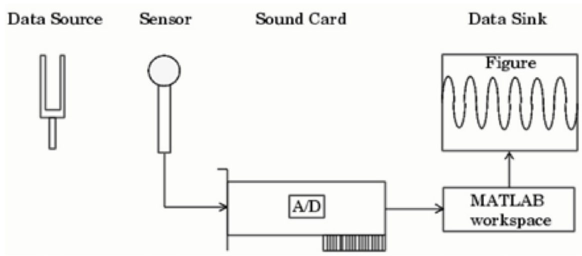

Figure 5. Set-up for the tuning fork labwork. The tuning fork vibrations are captured by a microphone. The resulting signal is transferred to the PC using a sound card. A Matlab program is used to collect data.

pressure variations caused by the vibrating tuning fork. The students are asked to write a fast Fourier transform program using the Matlab program. After gathering data, the fast Fourier transform program is used to convert the digital data into the frequency of the tuning forks. The main objective of this labwork is the understanding of the fast Fourier transform. The students are asked to draw conclusions about the relation between the resonant frequency and the tuning fork tine length.

Labwork about recording the skin temperature

This labwork explores two methods of temperature data acquisition: a LabView based virtual instrument and a Matlab program. These two methods are used to obtain sampling of students' skin temperature. The students are asked to build a virtual instrument for measuring the skin temperature using LabView. This virtual instrument is connected to an integrated temperature sensor in an NIDAQ signal accessory and is used to collect data of students' skin temperature.

The Matlab program is also used to collect data of skin temperature using the same temperature sensor. The data collection using the Matlab program with the data acquisition toolbox is illustrated in Figure 6. The students were asked to collect skin temperature data using both methods. These values were then used to calculate and compare various statistical parameters, such as the standard deviation of the temperature distribution, the temperature average (mean) and the temperature root means square (RMS).

Labwork about the cantilever beam vibrations

The purpose of this labwork is to explore the effects of dimensions and material on the cantilever beam's frequency response characteristics. The response of the cantilever beam under harmonic excitation is simultaneously measured using a strain gage and a piezoelectric accelerometer, and

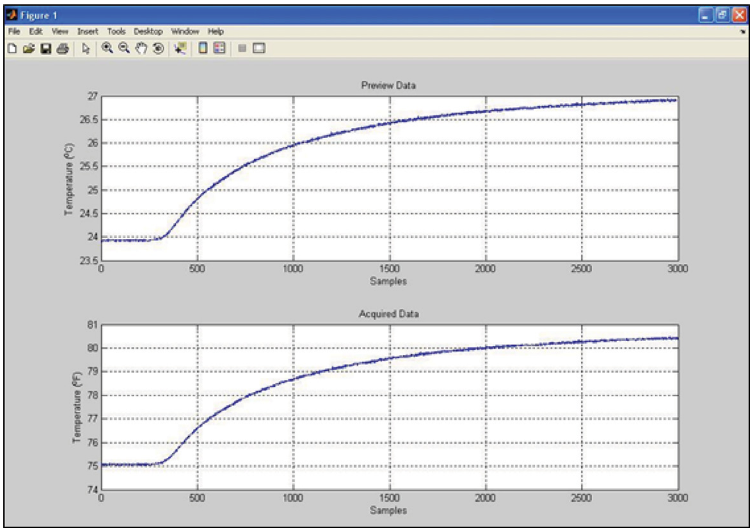

Figure 6. Sample data collected using Matlab program.

compared with real time theoretical response. Cantilever beams made from two different materials, steel and composite material, and with different lengths are used. During the labwork session, the beam is secured at one end. An impulse force is applied to the free end of the cantilever beam using an impulse hammer, in order to determine the system's natural frequency and the damping coefficient. In addition the effect of material's type on the speed of the wave through the beam is examined.

A Vishay strain gage is mounted about 40 cm from the free end of the beam and measures the average strain under its area of application. The strain gage calibration is required in order to determine the strain variation corresponding to the beam vibrations. In this respect a micrometer is used to deflect the beam and produce variable strain. The strain gage calibration is performed using a P3 strain indicator recorder and a digital multimeter to measure the corresponding voltage.

A piezoelectric accelerometer measures the acceleration at the free end of the beam and is mounted about 2.5 cm from the free end. After the beam strain gage is calibrated an impact hammer is used to apply an impulse force at the free end of the beam. The cantilever beam with the strain gage and the accelerometer mounted on it is shown in Figure 7.

Using a program written in Matlab the informations from the strain gage, accelerometer and impact hammer are recorded. The recorded graphs are expressed in volts versus time as shown in Figure 8. The students are asked to convert the data expressed in volts into microstrains corresponding to the strain gage, m/s^2 corresponding to the accelerometer and Pa corresponding to the impulse hammer. Microstrain versus time, acceleration (m/s^2) versus time and force (Pa) versus time curves

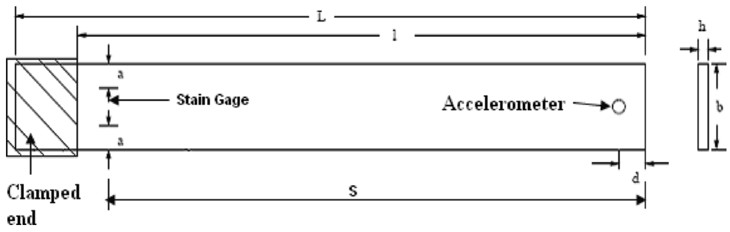

Figure 7. Cantilever beam with the strain gage and the accelerometer marked.

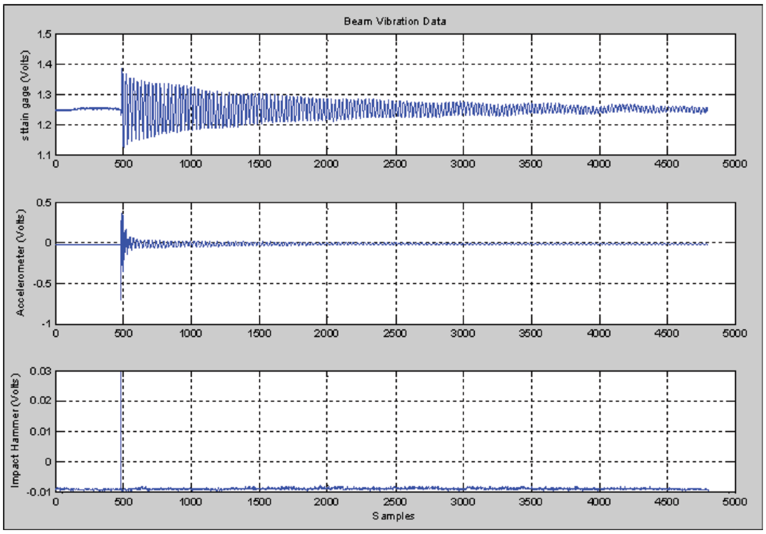

Figure 8. Plotted data acquired using the Matlab program written especially for this labwork.

are plotted. The stress versus time and the stress strain curves are also plotted. The damping coefficient and the theoretical damped frequency are calculated and compared with the experimental values [37]. The elastic speed of the vibration wave is also calculated.

HEAT TRANSFER

This classical undergraduate course covers the three modes of heat transfer: conduction, convection and radiation. In addition to grounding students in the fundamentals of heat transfer, our objective in revising this course was to broaden the student's perspective of the subject by incorporating important topics not commonly covered in undergraduate courses and including material on emerging technologies. A key constraint on restructuring the course is that new mathematical tools will not be needed. The addition of new material required eliminating and abridging some topics while preserving the fundamentals of conduction, convection and radiation. Based on many years teaching this course it was decided to: (1) Eliminate a chapter on two-dimensional conduction, the derivation of Blasius and Pohlhausen solutions, and radiation in three-surface and multi-surface enclosures. (2) Abridge a chapter on convection correlation equations. It is worth noting that this abridgment proved to be an effective pedagogical approach to correlation equations. Instead of presenting and discussing individual equations, students are taught a systematic procedure for selecting an appropriate equation for a specific application. The procedure is based on understanding the need for the heat transfer coefficient, the role of geometry, the limitations on the range of parameters, the nature of flow, and the determination of properties.

The selection of new material proved more challenging than eliminating subjects. The following topics were selected among several considered: Conduction with phase change, heat transfer in living tissue, and heat transfer in microchannels. A brief summary of each follows.

Conduction with Phase Change. Recent interest in this area has focused attention on applications to thermal storage, cryosurgery, cooling of microelectronics and processing of nuclear waste material. Although mathematical solutions are complex due to the non-linearity of the problem, a common simplified model based on the quasi-steady approximation makes it feasible as an undergraduate subject. Students learn to analyze and solve problem such as the freezing of steak, thawing of an apple and freezing of a lake.

Heat Transfer in Living Tissue. The past two decades have seen significant expansion of bioengineering. Knowledge of basic biology and physiology is essential in tackling certain interdisciplinary bioengineering problems. Although heat transfer in living tissue is usually covered in graduate courses, a simplified treatment was specifically developed for undergraduate students. Blood flow and vascular architecture are presented with the aid of Figure 9. One of the key requirements for analyzing heat transfer in tissue is the formulation of an appropriate bioheat equation. The simplest and most popular model is Pennes bioheat equation. Pennes equation (1) is formulated with emphasis on its analogy with the familiar fin equation.

$$\frac{\partial^2 T}{\partial x^2} + \frac{\rho_b c_b \dot{w}_b}{k}\left(T_{a0} - T\right) + \frac{q_m'''}{k} = \rho c_p \frac{\partial T}{\partial t} \tag{1}$$

This equation is used to analyze heat transfer in the arm and digit. By modeling certain organs as fins, this equation is used to study heat transfer in the rat tail (Figure 10), elephant ear (Figure 11) and the armor of dinosaur Stegosaurus (Figure 12).

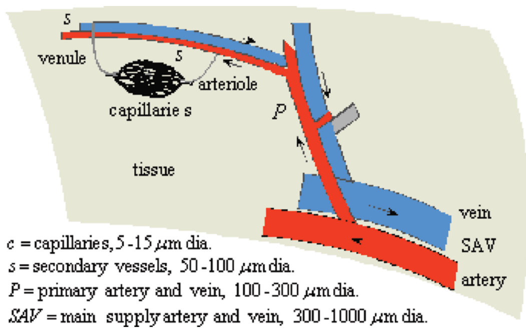

Figure 9. Schematic of vascular architecture.

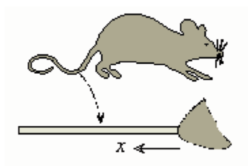

Figure 10. Fin model for rat tail.

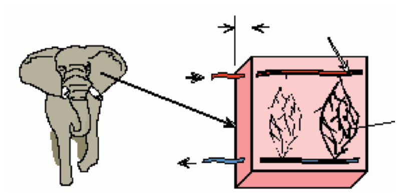

Figure 11. Fin model for elephant ear.

Another important application is tissue freezing associated with cryosurgical probes. This application makes use of conduction with phase change presented above. Figure 13 is a one-dimensional model of tissue freezing over a planar probe.

Heat Transfer in Microchannels. The need for efficient cooling methods for high heat flux components focused attention on the cooling features of microchannels. Microchannels are used in a variety of MEMS such as micro heat exchangers, mixers, pumps, turbines, sensors and actuators. Material on this emerging technology was specifically prepared for undergraduate students. Basic concepts such as continuum and thermodynamic equilibrium are reviewed and the Knudsen number is defined. To avoid complications, consideration is limited to ideal gas. In addition, the analysis is limited to the slip flow regime where the range of the Knudsen number is between 0.001 and 0.1.

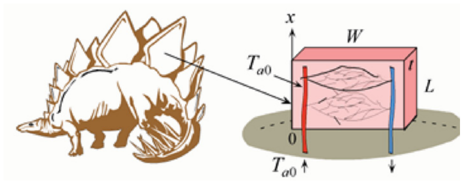

Figure 12. Fin model for dinosaur armor.

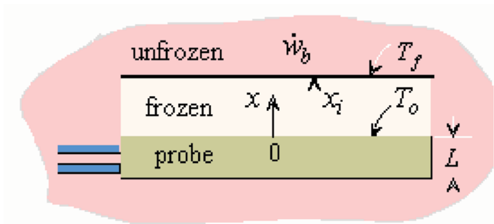

Figure 13. Planar cryosurgical probe.

This is an important case since for such microchannels the continuum model is valid while the no slip boundary condition fails. Similarly continuity of temperature at a boundary also fails and is replaced by a temperature jump condition. Based on these considerations, analysis of flow and heat transfer in the following microchannels is examined:

(i) Circular Couette flow. This common problem is modeled as a rectilinear Couette flow, shown in Figure 14, with velocity slip and temperature jump at the two surfaces.

(ii) Poiseuille flow: Uniform surface flux. Velocity and heat transfer solutions for Poiseuille flow between parallel plates are obtained taking into consideration velocity slip and temperature jump at the boundaries. The variation of the Nusselt number with Knudsen number is determined. Figure 15. shows the dramatic decrease in Nusselt number as the Knudsen number is increased from the macro case of $Kn = 0$ to the micro case of $Kn = 0.12$.

(iii) Poiseuille flow: Uniform surface temperature. The previous case is repeated with specified surface temperature and a plot of Nusselt number vs. Knudsen number is obtained.

SYSTEMS MODELING, ANALYSIS AND CONTROL

The study of System Dynamics and Control requires a genuine multi-disciplinary approach to integrate principles in various engineering disciplines (mechanical, electrical, computer, information

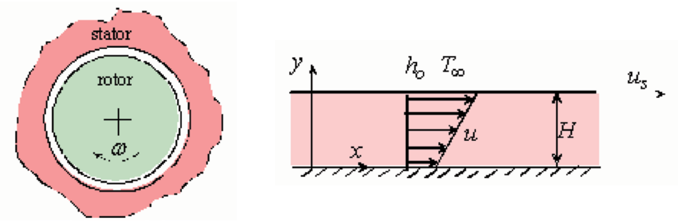

Figure 14. Velocity slip in microchannel Couette flow.

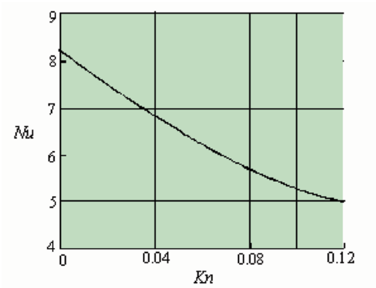

Figure 15. Knudsen number effect of Nussel number for airflow between parallel plates.

technology, etc.) to develop optimal strategy for solving a contemporary engineering problem. Many educators have developed various forms of pedagogy for the improvement of teaching-and-learning of this important subject [38–47]. The current effort adopts an integral analytical-numerical-experimental pedagogy for a required course – *ME 41100: Systems Modeling, Analysis and Control* (4 credits, 3 lecture hours and 3 laboratory hours), which is one of three courses in the area of mechatronics and controls offered in this curriculum. The other two courses are ME 31100: Fundamentals of Mechatronics (required, 3 credits, 2 lecture hours and 3 laboratory hours) and ME 51100: Advanced Mechatronics (technical elective, 3 credits, 2 lecture hours and 2 laboratory hours).

As shown in Figure 16, ME 41100 lies at the center of the Mechanical Engineering curriculum. The pre-requisites required for this course include mathematics (calculus, differential equations, complex variables, linear algebra, etc.), engineering science courses (dynamics, mechanics of materials, fluid mechanics, heat transfer, electric circuits, etc.), MATLAB-based computer and numerical techniques, and mechatronics-based laboratory techniques (e.g., knowledge of various electro-mechanical-optical sensors, digital data acquisition, characteristics of measurement systems, engineering statistics and regression analyses, etc.). In short, this course serves as the culmination of our engineering science portion of the curriculum. Students are expected to apply the knowledge acquired from this course

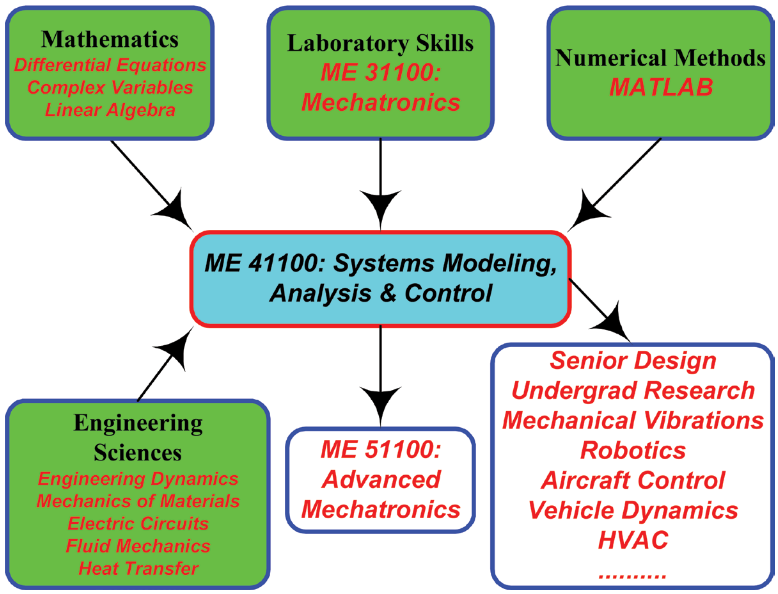

Figure 16. Centrality of the systems course in the ME curriculum

to almost all advanced courses during their senior year. These courses include, but are not limited to, senior design projects, advanced mechatronics, mechanical vibrations, robotics, aircraft stability and control, vehicle dynamics, HVAC, etc.

One of the major activities the Department undertook for the preparation of ABET visit in Fall 2004 was the reform of ME 41100. Previously, this course was split into two required courses - ME 42100: Systems Modeling, Analysis and Control (3 credits, 3 lecture hours) and ME 54300: Dynamics and Controls laboratory (1 credit, 3 laboratory hours). These two courses were sequential; that is, ME 42100 was the pre-requisite of ME 54300. As illustrated in the above figure, students need extensive background in analytical, numerical and experimental skills to learn well in ME 41100, the system dynamics and control course. However, in the old curriculum, this course was offered as a traditional engineering-science type of course with only 3 hours for lecture, which was not enough to cover the whole gamut of mechanical-engineering related systems, such as translational, rotational, electrical, electromechanical, pneumatic, hydraulic, thermal systems, etc.

The reform result is very encouraging. As discussed later, the score of our ABET course survey of ME 41100, in comparison with those of ME 42100 and ME 54300, has risen steadily from below 60 to around 80. Such a drastic change is not merely due to the change of sequential offering of ME 42100 and ME 54300 to the version of parallel offering. It is our belief that the improvement is

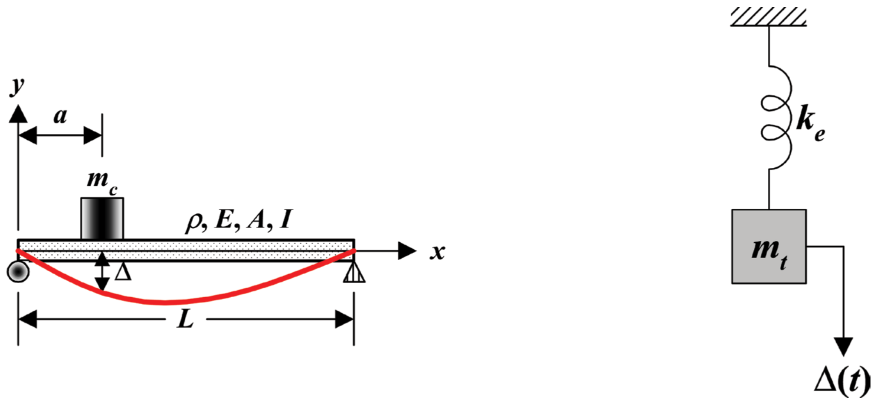

Figure 17. Sample homework problem.

mainly due to the implementation of several educational reform activities into the new version of ME 41100.

Objectives and Strategies of the Course Reform

The main goal of the course reform in ME 41100 was to help students gain useful knowledge and skills in the general area of system dynamics and control. Such knowledge and skills are necessary for the success in students' future professional careers (including graduate studies) and in life-long learning. In order to achieve this goal, students in this class solve problems and explore issues in system dynamics and control using engineering analysis, computation and experimental techniques. Upon completion of the course, students are expected to have developed abilities to identify and formulate real-world engineering problems, carry out background research, think creatively, work individually and in teams, synthesize information of various attributes, assess results, and communicate with others effectively.

To accomplish these objectives, we adopted a strategy emphasizing: (1) collaborative learning by student teams for problem solving, (2) just-in-time integral learning using analytical, computational and experimental approaches, (3) close linkage between mathematics skills and engineering applications, (4) student-initiated knowledge exploration, including exposure to emerging technologies. In short, this course reform places learning in students' own hands, emphasizes communication skills (both oral and written), encourages team work and development of people skills with the expectation of developing an ability for life-long learning.

The first step taken in this course was the revision of grading system. In the old mode when the course was split in two sequential courses: ME 42100 and ME 54300, the grading system was:

homework (10%), mid-term exams (60%), and final exam (30%) for the former, and exam (20%) and lab reports (80%) for the latter. In the current mode: ME 41100 (4 credits, 6 lecture-laboratory hours), the grading distribution is homework (36%), lab reports (18%), exams (25%) and final group presentation and report (21%).

Traditionally exams are used as the main assessment tool to evaluate a student's progress. However, since most, if not all, students tend to prepare for an exam seriously only a few days before, their learning usually is sporadic and the hastily acquired knowledge may be easily forgotten after the exam. Hence, two exams, each counting as 12.5% toward the course grade, are given to test students' accumulated knowledge in the middle and at the end of the semester. On the other hand, in order to reflect the new grade distribution system, the current course reform stresses comprehensive homework assignments, integral analytical-computational-experimental lab reports and final group presentation and report, which together count for 75% of the course grade. We believe that knowledge gained through these three non-exam oriented assessment tools will be etched into students' memory permanently and pave way for the course to achieve the afore-mentioned educational objectives.

Comprehensive Homework Approach

As stated above, homework assignment in the old mode counted only as a small fraction of the grade and the problems were frequently taken out of textbook directly. In general each problem represents a simple practice and is only intended to present a single concept of the chapter. To get the answer very often students need only to choose a proper equation given in the chapter. Since these concepts, though closely connected, may appear independently among those dispersive homework problems, for most of students it may be difficult to see the overall picture showing how these concepts relate to each other and are linked to other subjects in the curriculum, i.e., the pre- and co-requisites. Innovative homework assignments were designed to induce students' learning from past experience, i.e., prerequisites, as well as future advanced study. For instance, in one of the homework assignments, students were asked to find the equivalent spring constant and mass of a simply-supported beam loaded with a concentrated mass, as shown in Figure 17.

The problem is related to one of the prerequisites of the course: ME 33000: Mechanics of Materials. In order to find the equivalent spring constant and mass, students will need the results of beam deflection due to an equivalent concentrated force. The beam deflection may be obtained from a conventional Mechanics of Materials textbook. To demonstrate that background knowledge from Mechanics of Materials is needed, students are asked to solve this problem through the following steps:

a. Generate a free-body diagram to determine if the beam is statically determinate or indeterminate.

b. If the beam is statically determinate, find the reactions and the shear and moment distributions.

c. Obtain the beam deflection and slope based on the results in step **(b)** if the beam is statically determinate. On the other hand, if the beam is statically indeterminate, obtain the reactions, the shear and moment distributions, and the beam deflection and slope using the more complicated approach.

d. Determine the equivalent spring constant and mass of the beam using the concept of energy equivalence.

In the old mode of teaching, steps **(a)** to **(c)** were considered covered in the Mechanics of Materials course. Only step **(d)** was considered to belong to system dynamics and control. However, without a thorough review of steps **(a)** to **(c)** and acquiring the segmented knowledge by executing only step **(d)**, a typical student may have difficulty to visualize the full picture linking these two basic subjects in engineering science: Mechanics of Materials and System Dynamics and Control.

Another feature of the comprehensive homework approach is to guide students through uncharted waters. In this approach, students were asked to work on homework assignment based not only on the knowledge they acquired in this course, but also on additional reading assignments taken from advanced study in system dynamics and control. For instance, the textbook adopted in this course is: K. Ogata, *System Dynamics*, 4th ed., 2004, which is suitable for a junior course such as ME 41100. In this textbook students learn basic dynamics for pneumatic systems as well as fundamental concepts in the proportional-integral-derivative (PID) control. In one of their homework assignments: Pneumatic PD Controller, students are asked to study the section of Control of Pneumatic Systems, taken from an advanced textbook by the same author, *Modern Control Engineering*, 4th ed., 2002, *pp*. 158–175, which is more suitable for a first-year graduate level course in feedback system control. The functions, construction, applications and limitation of a pneumatic proportional (P) controller is explained fully in this self-study reading assignment. Students are asked first to learn this advanced, yet related, subject by themselves, then to apply this self-study knowledge to explain the pertinent attributes of a pneumatic proportional-derivative (PD) controller.

Integral Analytical-Computational-Experimental Learning

In the old sequential mode of the curriculum, students did not conduct experiments in system dynamics and control until they had completed the learning of all theories and analytical/numerical techniques. Without hands-on experience, some students, if not all, may be hampered from acquiring knowledge in engineering. Furthermore, since theories and experiments were learned in two separate courses: ME 42100 (theories) and ME 54300 (experiments), in the past a few students postponed the taking of ME 54300 several semesters after they had taken ME 42100, thus diminishing the effect of learning the subject in continuation.

With the augmented credits and hours in the new format, the instructor now has the flexibility to teach subjects in an integral analytical-computational-experimental approach and make it easier for students to have full understanding of the subject.

Final Group Presentation and Report

In lieu of the traditional final exam, students are asked to make a final group presentation with a report. Indeed, the team, which usually consists of three to four students, is formed at the beginning of the semester and is the basis for the afore-mentioned collaborative learning and experimental group. Topics of the final presentation must be related to proportional-integral-derivative (PID) control. Each student team needs to define its engineering problem and comes up with the governing equations of the problem for analysis and design. Specifically, the presentation should conform to feedback control of a physical plant subject to reference, disturbance and noise inputs in the form of step, ramp and parabolic functions. The resultant controlled output and the actuating error signal are of particular interest. Strong encouragement is given to topics of interdisciplinary nature and/or applications in emerging technologies (e.g., MEMS/mechatronics, nanotechnology, intelligent systems, smart structures, adaptive materials, biomedical engineering, innovative energy-power systems, etc.). The rationale of having this learning activity at the culmination of the semester, as mentioned earlier, is to help students develop abilities to identify and formulate real-world engineering problems, to carry out background research, to think creatively, to work individually and in teams, to synthesize information of various attributes, to assess results, and to communicate with others effectively. In a nutshell, it places learning in students' own hands after they have accumulated enough background knowledge. Such training is very crucial for their capability for life-long learning. A sample of topics studied is listed below:

- Lateral Directional Dynamic Stability and Control of an Aircraft
- PID Controller Tuning for a CVD Process
- Control of Turbine Blade Vibration
- Deck Stabilization Using Hydraulic Circuit
- Control Optimization of Nonlinear Dynamic System: Rocket Trajectory
- Yaw Control of a Wind Turbine

ASSESSMENT RESULTS

To ascertain the effectiveness of the changes introduced assessment was carried out for all courses, some in conjunction with ABET evaluation.

Assessment of ME 33000, Mechanics of Materials

At the end of each semester, ABET course survey is conducted. Students are asked to self-evaluate their learning according to seven course outcomes, which are:

1. Knowledge of calculating stresses, strains, and deformations for axial loading
2. Knowledge of calculating stresses, strains, and deformations for torsion
3. Knowledge of calculating stresses, strains, and deformations for pure bending
4. Knowledge of calculating stresses, strains, and deformations for transverse loading of beams
5. Knowledge of solving statically indeterminate problems
6. Knowledge of calculating principal stresses
7. Knowledge of designing beams for strength.

Since Spring 2002, the Department requires ABET course surveys to be conducted for each class section, as one of our ABET assessment tools. The survey questions, called Course Outcomes, of a given course were designed by a faculty coordinator, who may not always be the instructor. Students pick one of three choices: course outcome satisfied, somewhat satisfied and not satisfied. The answers are then converted to a score on a scale of 0 to 100.

Tables 1 and 2 below summarize the ABET course survey results before and after the reform. To exclude other factors, only the results from the sessions taught by the same instructor, are listed. The tables show the survey result for each outcome in each semester. The last two columns are the number of students surveyed and the survey mean. As one can see from the tables, the overall survey mean improved slightly after the reform. The fact that the improvement was not significant is understandable since the course outcome scores were relatively high to begin with. To assess students' performance the grades before and after the reform are also shown in Tables 1.A and 1.B. It appears that students' grades suffered after the reform. The introduction of new materials may have caused the drop in grades.

Assessment for the ME 31100 Mechatronics

In ME 31100, Fundamentals of Mechatronics course the students are requested to solve classic homeworks and also labworks. Table 3 shows students' grades for the regular homeworks and for the labworks. As illustrated in Table 3 student performance for the labworks is better than the performance for regular homeworks. On average, more students received A's and B's for labwork than for regular homeworks.

In the Fall 2008, Spring 2008 and Fall 2009 semesters a survey was conducted to assess students' interest in conducting the labworks assignments. The survey results are given in Tables 4–7.

Currently, because the survey showed the positive opinion of the students for "labwork" type assignments, we continue to give the students "labwork" type assignments during the mechatronics course.

				Student Grade					
Semester	Students Enrolled	Students Surveyed	Survey Mean	A	B	C	D	F	W
2003 Spring	21	21	87	38%	24%	28%	0	5%	5%
2003 Fall	16	13	83	31%	37%	13%	6%	0	13%
	37	34	85.5	35%	30%	21%	3%	3%	8%

Table 1. ME 33000 ABET Course Survey Results and Student Grades (Before Reform).

				Student Grade					
Semester	Students Enrolled	Students Surveyed	Survey Mean	A	B	C	D	F	W
2007 Spring	23	18	86	13%	39%	22%	4%	9%	13%
2007 Fall	26	20	89	27%	35%	11%	0%	23%	4%
2008 Fall	27	20	92	30%	22%	33%	0%	11%	4%
	76	58	89.1	24%	32%	22%	1%	14%	7%

Table 2. ME 33000 ABET Course Survey Results and Student Grades (After Reform).

Assessment for the ME 43300 Heat Transfer course

To evaluate the impact of the added material on course outcomes students were surveyed at the end of the term. Students were asked to rate six outcomes concerning (1) learning heat transfer fundamentals, (2) ability to solve a wide range of heat transfer problems, (3) using heat transfer analysis in design, (4) applying computers to generate solutions, (5) performing simple heat transfer experiments at home, and (6) developing a systematic problem solving methodology. Scores for the four semesters preceding the introduction of the new topics were compiled and are shown in Table 8. The average score for the six outcomes of the four terms is 87.5%. The score for two semesters using the new curriculum is 82.5%. The drop in student's evaluation of the course may be due to the introduction of new material that is relatively complex for undergraduate students. It should also be noted that not enough data was collected to carry out statistical analysis. In addition, the scores for questions 5 and 6 for the spring 2009 were lost in the data reduction process. These two

	Regular homework				Labwork				Class size
Grade	A	B	C	D	A	B	C	D	
Spring 2009	22%	46%	24%	8%	26%	48%	20%	6%	29
Fall 2009	20%	43%	26%	11%	22%	50%	20%	8%	31
Spring 2008	18%	43%	28%	11%	24%	49%	23%	4%	32
Fall 2008	19%	41%	25%	15%	20%	51%	21%	8%	33
Spring 2007	23%	45%	20%	12%	21%	55%	18%	6%	29
Fall 2007	14%	49%	23%	14%	18%	59%	13%	10%	30
Spring 2006	16%	39%	25%	20%	16%	53%	21%	10%	28
Fall 2006	18%	35%	32%	15%	20%	55%	17%	8%	27
Spring 2005	21%	41%	28%	10%	24%	50%	22%	4%	24
Fall 2005	26%	44%	14%	16%	22%	46%	24%	8%	18
Average	20%	43%	24%	13%	21%	52%	20%	7%	28

Table 3. Students performance for classic homework assignments and labwork assignments.

	not at all	very little	average	more than average	very helpful	Class size
Fall 2009	0	0	30%	36%	34%	31
Spring 2008	0	0	22%	36%	42%	32
Fall 2008	0	0	34%	30%	36%	33

Table 4. Students' answers to the question: Did the labwork help you to understand the subject better?

	boring	slightly boring	average	more than average	interesting	Class size
Fall 2009	0	0	33%	34%	33%	31
Spring 2008	0	0	26%	41%	33%	32
Fall 2008	0	0	35%	36%	29%	33

Table 5. Students' answers to the question: Were the labwork interesting and did you enjoy doing them?

questions are normally given high scores. This resulted in the lowest overall outcome score for the Spring 2009 semester.

Students' performance as indicated by the grades they received is shown in Table 8. Changes in the percentage of students receiving grades A and B before and after the introduction of new material are essentially comparable. However, the reformed curriculum resulted in a significant reduction

	not at all	very little	about right	right	too much	Class size
Fall 2009	10%	8%	37%	13%	32%	31
Spring 2008	2%	14%	38%	14%	32%	32
Fall 2008	7%	14%	38%	12%	29%	33

Table 6. Students' answers to the question: Did the labwork take up too much of your time?

	no opinion	not recommend	partially recommend	recommend	strongly recommend	Class size
Fall 2009	3%	14%	34%	34%	15%	31
Spring 2008	6%	6%	36%	38%	14%	32
Fall 2008	7%	5%	37%`	35%	16%	33

Table 7. Students' answers to the question: Will you recommend the labwork pedagogy to be adopted in other courses?

Semester	Me 433 Heat Transfer course outcome number						Mean Score	Student Grade					
								A	B	C	D	F	W
Before Reform	1	2	3	4	5	6							
S 2002	89	85	78	68	87	85	82	18%	15%	52%	4%	7%	4%
F 2002	96	91	88	70	96	98	90	9%	35%	56%			
S 2003	90	81	83	71	90	89	84	11%	21%	57%	11%		
F 2003	100	95	95	75	98	98	94	17%	39%	39%	5%		
Average								14%	27%	51%	5%	2%	1%
After Reform													
F 2008	93	84	86	74	86	86	85	9%	27%	32%	5%	23%	4%
S 2009	60	89	83	89	*	*	80	12%	29%	26%	17%	9%	7%
Average								10%	28%	29%	11%	16%	6%

*Missing scores

Table 8. ME 43300 ABET Course Survey Results and Student Grades before .

in the percentage of C grades and an increase in the D, F, and W grades. Although we do not have sufficient data to state with certainty the reason for this development, one possible explanation is the complexity of the added material.

Assessment for ME 41100 Systems Modeling, Analysis and Control course

Results of the ABET survey for the System Dynamics and Control course in the Fall 2006 semester are given in Table 9 below:

In Table 9 above, the means were calculated by giving a weight of 1.0, 0.6 and 0.0 to the Strong, Partial and None answers, respectively. The above weights were used to be able to compare student performance with other Grove School of Engineering (GSOE) courses. As shown in the last row of the table, about half of the class felt they had gained strong knowledge/ability whereas the other half considered they had acquired partial knowledge/ability of system dynamics and control from the course. Students also felt more comfortable when the knowledge/ability is in time domain (Questions 1, 2, 6 and 8) while they felt less comfortable when dealing with problems in frequency domain (Questions 4, 5 and 7). This is understandable due to the two facts:

a. Most of us are more intuitive in time domain than in frequency domain.

b. The subjects in frequency domain are covered in the last three weeks, which are only one-fifth of the contact hours of the course. That means students did not have enough time to digest what they had just learned before taking the survey, which is usually given at the end of the semester.

Finally, Tables 10 and 11 below summarize the ABET course surveys from Spring 2002 until Fall 2006. Other than the Spring 2002 semester, all the remaining classes were taught by the same instructor. Table 10 shows results of the ABET course surveys conducted according to the old pedagogy; whereas the Table 11 depicts results after the reform pedagogy was implemented. As one can

	Survey Question (Course Outcome)	N	Knowledge Gain			
			Percentage of N			Mean
			None	Partial	Strong	
1	Ability to model various physical systems using techniques of differential equations. Ability to model and analyze these systems using MATLAB,	20	0	30	70	88
2	Knowledge of time-domain responses of first and second order systems. Ability to solve time response problems using MATLAB.	20	0	30	70	88
3	Knowledge of control systems in time domain, etc. Ability to use MATLAB for design and performance prediction of control systems in time domain.	19	0	70	30	72
4	Knowledge of frequency-domain responses of dynamic systems and vibration problems. Ability to solve frequency response and vibration problems using MATLAB.	20	0	70	30	72
5	Knowledge of control systems in frequency domain. Ability to use MATLAB for design and performance predictions in frequency domain.	20	5	65	30	69
6	Ability to conduct time-domain mechanical system experiments and compare with theoretical prediction.	20	0	40	60	84
7	Ability to conduct frequency-domain vibration experiments and compare with theoretical prediction.	20	0	55	45	78
8	Ability to conduct various control experiments and compare with theoretical prediction.	20	0	35	65	85
	Average		1	49	50	80

Table 9. Course outcomes for the Systems Modeling course (Fall 2006).

Semester	Students Enrolled	Students Surveyed	Survey Mean	Student Grade					
				A	B	C	D	F	W
2002 Spring*	19	16	51	5%	32%	32%	21%	5%	5%
2002 Fall	24	18	56	25%	38%	29%	4%	0	4%
2003 Spring	14	14	64	0	64%	22%	4%	4%	0
	57	48	56.7	12%	42%	28%	10%	4%	4%

Note: (*) The Spring 2002 class was taught by another instructor.

Table 10. ME 41100 ABET Course Survey Results and Student Grades (Before Reform)

Semester	Students Enrolled	Students Surveyed	Survey Mean	Student Grade					
				A	B	C	D	F	W
2003 Fall	5	5	81	40%	20%	20%	20%	0	0
2004 Spring	8	8	86	25%	50%	25%	0	0	0
2004 Fall	20	16	79	35%	30%	20%	10%	0	5%
2005 Spring	26	25	74	23%	58%	15%	0	0	4%
2005 Fall	23	19	80	17%	39%	44%	0	0	0
2006 Spring	11	7	79	27%	27%	27%	0	0	19%
2006 Fall	22	20	80	23%	45%	32%	0	0	0
	115	100	78.8	25%	41%	27%	3%	0	4%

Table 11. ME 41100 ABET Course Survey Results and Student Grades (After Reform).

see from these two tables, the survey mean (which is proportional to the students' confidence in their knowledge gain) improved drastically from a score of 56.7 to 78.8 while the overall academic performance had also improved impressively. For example, after the reform, on average the percent of students getting A and B grades increased from 54% to 66%.

SUMMARY AND CONCLUSIONS

All the courses in the Mechanical Engineering curriculum were systematically modified to incorporate emerging technologies and/or new teaching methodologies. The modification was course specific and involved incorporation of new topics, examples from emerging technologies, new software, hands-on experiences, reverse engineering, project based learning, home experiments, etc. The modification was tailored to the need of the specific course. From the limited assessment conducted, at least for the assessed courses the following conclusions can be drawn:

a. In the laboratory courses students found the subject more interesting and more enjoyable
b. Students' grades improved in some courses, but deteriorated in others
c. Overall academic performance of students also improved in some courses

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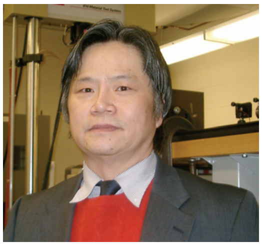

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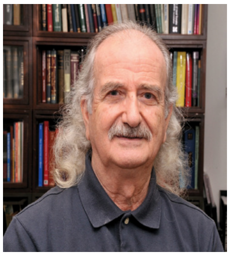

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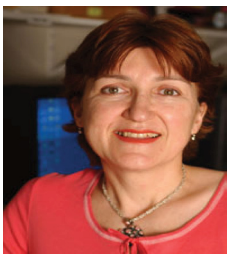

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