

PROJECT DESCRIPTION

1. INTRODUCTION

This project represents the implementation phase of an NSF “Planning Grant for the Department Level Reform of Undergraduate Engineering Education” awarded to the City College of New York (CCNY) Mechanical Engineering (ME) Department in October 2002. This systemic reform of the curriculum will be undertaken in partnership with the American Society of Mechanical Engineers (ASME). The Mechanical Engineering Department 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 three 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 (Grinter, 1955, pp. 25-66). 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, the undergraduate engineering science curricular component of the CCNY department of Mechanical Engineering largely follows this traditional pattern and is in need of reform. It should be noted that even in the face of revolutionary advances in technology, the basic philosophy of the report still holds: *No real understanding of technology is possible without basic science*. Thus, the challenge is to enhance the content of today’s engineering curricula without sacrificing the fundamentals. Recent developments in our department have 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 place us far from the cutting edge of technology. One indication of this problem is that students in senior design courses are often uncomfortable with design projects sponsored by our research laboratories or by industry when they depart from the traditional mechanical engineering knowledge base and involve 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.

Industry: According to an NSF/ASME study of the product realization process (PRP), industry managers place the highest value on the following elements of engineering: Teamwork, Communication, Design for Manufacture, CAD and Professional Ethics (Valenti, 1996). As Bucciarelli points out in his study of working engineers, industry practice is rarely reduced to the set-piece formulas and algorithms of traditional engineering education: “Most engineering practitioners know that designing is not simply a matter of synthesizing solutions to independent problem sets. Although few of the complexities of engineering design show up in the undergraduate classroom, the working world of engineers is filled with negotiations across specialties, with decision making under uncertainty within contexts in which scientific principle is mixed in

with social, political, and financial ‘constraints’”(Bucciarelli, 1996, p. 110).

Science of Learning: A recent compendium of conclusions from cognitive research argues for the design of learning environments that incorporate three major principles: they must be *learner* centered, *knowledge* centered and *assessment* centered. “Teachers who are learner-centered recognize the importance of building on the conceptual and cultural knowledge that students bring with them to the classroom.” (National Research Council, 2000, p.134) Knowledge-centeredness implies a broad understanding of ideas in context: “Ideas are best introduced when students see a need or reason for their use. This helps them see relevant uses of knowledge to make sense of what they are learning.” (*Ibid*, p. 139) Assessment involves far more than traditional tests, papers and homework: “Effective teachers continually attempt to learn about their students’ thinking and understanding. They do a great deal of on-line monitoring of both group work and individual work... Appropriately designed assessments can help teachers realize the need to rethink their teaching practices.” (*Ibid*, p. 140-141)

Technological Literacy: Engineering education is of importance to society, not only because of engineers’ technical contribution, but also because of their role in communicating with the public about technology. Thus, communication skills are needed in order “to ensure that future engineers can convey complex technical concepts and principles to the lay public.” (National Academy of Engineering, 2002, p. 85) For similar reasons, students should develop an awareness of the social and environmental context of technology. According to an NSF panel, “redesigned engineering educational systems should better meet the needs not only of engineers, but also [of] the large number of students who will use their backgrounds in engineering and technology to serve them in their roles as literate citizens.” (National Science Foundation, 1995, p.9) These conclusions – from industry, cognitive science and the technological literacy movement – ought to form the basis for the systemic reform of undergraduate engineering education.

The third current compelling curricular reform is the inadequate supply of students interested in engineering. A recent study by the ACT (2003) reports that the number of high school seniors planning to study engineering dropped from nine percent in 1992 to six percent in 2002. The report also documents a drop in the number of female ACT test takers considering engineering careers, and a gap between aspirations of racial/ethnic minority test takers, as indicated by expressed interest in engineering, and their relevant preparation with more than basic coursework. A second report released by the Committee for Economic Development (CED, 2003) focused on three issues: lack of interest in scientific and technological careers among young people, poor quality of coursework, and inadequate teacher training. The studies point in the direction of an engineering workforce inadequate to satisfy the needs of U.S industry. Thus, there is a strong need for aggressive recruitment and retention efforts, especially efforts aimed at underrepresented minorities and women, and the design of an innovative curriculum that will attract them.

All three elements of the reform effort can reinforce one another. For example new teaching strategies may help in retention efforts, while incorporation of emerging technologies may generate excitement among prospective students and interest them in engineering.

Thus, the main objective of this proposal is 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.
- b) introduction of new teaching strategies focused on student learning, and
- c) undertaking recruitment and retention efforts to ensure adequate preparation of the emerging workforce for the needs of U.S industry.

The reform effort will be undertaken through partnership between City College and the American Society of Mechanical Engineers (ASME). Participation of ASME will make it likely that outcomes of this project will achieve a broad national and international impact.

2. THE PLANNING PROCESS

In October 2002 the Department received an NSF planning grant to initiate the curriculum reform process.

In November 2002, a two-day retreat was held to discuss the reform issues and planning activities. Attendees included the entire fulltime ME faculty, three graduate teaching assistants and two elected undergraduate student representatives. After discussing the various reform issues, the participants split into three teams, each responsible for one of the following tasks:

- a) Identify emerging technologies to be incorporated in the ME curriculum
- b) Identify new teaching strategies to enhance student learning
- c) Identify strategies to increase the number of underrepresented minorities and especially women.

Over the next two months the teams met to accomplish these tasks. During the same time the chair and a senior faculty member participated in two department heads' meetings at the ASME Congress. The meetings were devoted to the incorporation of nano- and biotechnology into the ME curriculum. The Department also invited Prof. Steinberg who holds a joint appointment in the City College Physics and Education departments, to give a seminar on current research on learning and teaching of college physics. Prof. Sadegh contacted various industrial partners to solicit their feedback with regard to the changes contemplated in the curriculum (please see attached letters of support). In addition, Profs. Jiji and Delale contacted Smith College and Tufts University to learn about their successful strategies in attracting women to engineering. The Co-PI's also organized a meeting with female students in the ME Department. The purpose was to listen to their experiences at City College and learn about how and why they were attracted to engineering.

Based on all these sources, the three teams identified the emerging technologies and new teaching methods to be incorporated into the ME curriculum, and the strategies to attract minorities and women.

Parallel to this effort a group of faculty made contact with the American Society of Mechanical Engineers (ASME) to explore the possibility of their participation in this effort. ASME is the premier organization of the mechanical engineering profession and can provide meaningful feedback on the impact of the curriculum reform on the practice of engineering. The ASME received the idea enthusiastically and decided to collaborate in this effort. The activities that will be undertaken by ASME are explained throughout the proposal and in the section entitled "Collaboration with ASME". (See also letter of support)

It must be noted that the entire membership of the Mechanical Engineering faculty has participated in this process from the outset. Before starting to write this proposal a departmental meeting was held to determine who should serve as Co-PI's, their areas of responsibility, and obtain faculty agreement for the reform plan. (See attached resolution).

3. THE ELEMENTS OF REFORM

a) Incorporation of emerging technologies into the mechanical engineering curriculum

In this section, the new and emerging technologies are presented. In selecting these technologies the following criteria were used: significant or potential commercial applications, role in promoting technological literacy, intensity of related research, and general acceptance by the engineering community.

MEMS

Microelectromechanical systems (MEMS) are the class of devices that have components less than a millimeter in any dimension. These devices are used as sensors or actuators, analytical systems, optical switches, and power generators. Due to the availability of integrated circuit processing methods thousands of MEMS can be mass produced on a single six-inch silicon wafer, making them less expensive to produce than conventional parts. The scale of these devices enables engineers to manipulate the properties of their constitutive materials in order to enhance device performance. Integration of MEMS in the ME curriculum has become an important goal of engineering educators in order to prepare undergraduates for positions in academic research and industrial projects that incorporate MEMS technology into commercial and analytical products. Commonly cited examples of MEMS devices for mechanical engineering applications include microturbines for propulsion, microaccelerometers for automobiles, and micrometer-sized printer heads for inkjet technology. Additionally, mechanical engineers must also learn the techniques of micromanufacturing

that are used to fabricate these devices.

Advanced Materials

In conventional curricula engineering students are usually exposed to and learn to design with metals, alloys, ceramics and plastics. However, new and advanced materials are supplanting the conventional engineering materials at an accelerating pace. While some advanced materials such as polymer matrix composites are reaching maturity and have a wide spectrum of commercial applications, newer ones such as carbon nanotubes are in the research phase. Thus there is urgency in incorporating these new and advanced materials into the appropriate courses of the curriculum. These advanced materials are: composites, super alloys, metal foams, shape memory alloys, piezo and ferroelectric materials, carbon nanotubes and their composites.

Computer Aided Engineering

Computer Aided Engineering (CAE) refers to computer-based approaches to illustration of concepts, simulation of phenomena, analysis, synthesis, design and manufacturing. The availability of new commercially available software with outstanding pre- and post processing, graphical interfaces and visualization capabilities opens new opportunities for classroom instruction. Engineers with skills in the use of highly advanced software packages have a great potential for improving the industrial base of this country by shortening the time needed for the development and fabrication of a product.

The use of CAE software in the classroom helps students to understand course material better, explore new ideas and experiment with new designs that were intractable before. For example, the possibility of computing three-dimensional fields in fluid or solid mechanics opens new vistas in analysis and design.

Integration of CAE software packages into the curriculum is always challenging. The time available to teach and train the students in the use of these packages is always limited. As a result students may sometimes use the software without a complete understanding of its capabilities and limitations. Methodologies need to be developed that will check the reliability of the results.

Intelligent Systems/Electronics

Optimization of manufacturing can be quite difficult, as the dynamic processes require adaptive modeling and control. Current research suggests that manufacturing systems employing intelligence, non-determinism and self-organization can address a wide range of problems [Brezocnik *et al.* (2003)]. An example of the application of this kind of technology could be the development of production line robots that could respond intelligently to unexpected events. These systems may soon revolutionize manufacturing and thus should be introduced in the undergraduate curriculum.

Biotechnology

Biotechnology incorporates a wide variety of technologies that analyze biological systems. These include extremely diverse instruments such as genomic and proteomic sequencers, microarrays and drug delivery systems, as well as biochips and biosensors [Campitelli and Parton (2002)]. The current explosion of research in biotechnology is complemented by industrial products and patented inventions that are reshaping the technical requirements of future generations of engineers. As a result, existing ME classes such as Advanced Fluid Mechanics and Heat Transfer, will now highlight phenomena important in biotechnology, while newly-developed courses such as Micro/Nano Materials and Manufacturing will introduce students to practical requirements of biotechnology.

Nanotechnology

Nanotechnology broadly refers to technology, whose methodology takes advantage of components and features with length scales that approach nanoscale dimensions. It also refers to the manipulation of material at the molecular level. This area is inherently cross-disciplinary, cutting across physics and chemistry and embodying a wide range of platforms. One of the most successful developments in this area is that of carbon nanotubes, nanowires, which may have applications not only in material development, but also electronics. In the not so distant future, nanodevices will revolutionize the practice of engineering. Thus the inclusion of nanotechnology in appropriate courses is necessary.

Nontraditional Energy

Nontraditional energy technologies, such as geothermal, solar and wind already have some presence in the global energy market, and environmental concerns and “energy supply security” may increase investments in these alternative energy sources in the near future [Fells (2002) and McVeigh et al. (2000)]. A particularly successful area in alternative energy technology involves research and development of fuel cells by both academia and industry. Though limits exist that prohibit practical application at this time, fuel cells are expected to have a significant impact on vehicular travel. In fact, commercialization of fuel cells for industries requiring continuous guaranteed power, such as hospitals and factories is possible within the next few years [Burns et al. (2002)].

b) New teaching methodologies

A consensus has emerged among cognitive psychologists and educational researchers that traditional teacher-centered instructional methods are generally ineffective in motivating students to learn, promoting understanding, addressing prior concepts, or even conveying information (National Research Council, 2003, p.26). Research to support these conclusions has come from a variety of subject areas and educational levels, including college physics (McDermott, 1991). However, very little if any of this research has come from the field of engineering. In an attempt to remedy this problem, a national Center for Engineering Learning and Teaching has recently been funded at the University of Washington.

Major revisions will be undertaken in existing courses to reflect current knowledge about how people learn. In addition, new courses will incorporate the same understandings about effective pedagogy.

A variety of pedagogical strategies will inform new and existing courses. These are mutually supportive and overlapping. Each of these strategies contributes to a set of overarching goals, which are to stimulate critical thinking, foster the development of teamwork skills, and provide many opportunities for written, graphic, and oral communication. The basic repertory of strategies is summarized below:

Cooperative Learning: Research suggests that students often learn from one another as well as from the instructor (Bruffee, 1993). More generally, students who work cooperatively gain valuable experience in constructing knowledge the same way that engineers do: through participation in intellectual communities of practice. Collaborative learning can take many forms. Students may work in groups, in class or in lab, on traditional textbook or lab problems; they might work cooperatively on homework problems outside of class; or they could be challenged to solve deeper, more conceptual problems, such as the design of an experiment or prediction of a result.

Project-based learning: A major criticism of traditional instruction is that knowledge is fragmented into a multitude of component parts, with little if any opportunity to see how these fit together. For example, a typical textbook problem presents the data for analysis according to some predetermined algorithm, but may not suggest how the data was acquired, ways in which it might not conform to theory, possible sources of error, or implications for engineering applications. Students are often left on their own in fitting these pieces together, and many students rarely do. Project-based strategies begin by presenting problems more holistically, retaining the incomplete specifications, error sources and other uncertainties that characterize engineering practice. These problems generally include elements of analysis, simulation, and design; and often, design of an experiment and/or design, construction, and evaluation of a prototype.

Research methods: science and engineering content are too often presented as established fact, offering little hint of where current knowledge came from. Early research experiences can also serve as powerful incentives for students to pursue graduate studies, and ultimately research careers, and lead to personal relationships with faculty mentors. Some aspects of research that may be undertaken by students at the undergraduate level include literature searches, experiments, simulation, data analysis, and presentation of research outcomes.

Laboratory experience: conventional laboratory "experiments" are often designed to produce predetermined results, which simply confirm or demonstrate theoretical conclusions that are already known. One symptom of this problem is that students could write an acceptable laboratory report without ever visiting the lab.

Another is that data tables have already been set up for the students, and all they are expected to do is fill in the blanks. Far more learning can take place if the results of an experiment are not known in advance, and there are discrepant events that do not conform to the theory already presented. Students should be required to organize the data themselves, look for patterns in the data, and draw their own inferences about the meaning. In some cases, it is also possible for students to design the entire experiment. Another important component of laboratory experience could be home experiments, where students as part of their coursework conduct experiments at home and collect engineering data without the use of specialized equipment and instruments and then compare the results to those predicted by theory. (Jiji, *et. al*, 1996)

Independent Learning: engineering fields are constantly changing, and students will soon be called upon to learn new knowledge for themselves. The curriculum should encourage self-teaching, both in the context of traditional courses, and also for independent study credit. Activities that can be pursued independently, with appropriate faculty mentoring, include reverse engineering of existing products, data collection and analysis, literature and Internet searches, and design projects.

Interdisciplinary Learning: the barriers between traditional engineering disciplines are becoming less and less distinct, as reflected in such terms as "mechatronics," "quantum engineering," and "smart materials and structures." Increasingly, engineers will be expected to cross disciplinary boundaries via collaboration, learning new disciplines, and even switching fields. Undergraduate education should prepare students for these demands, for example, through design projects that cross disciplines, team teaching, and use of problem contexts from other disciplines.

Common Themes: most engineering problems are not completely specified. There are missing data points, social and economic factors that are not well understood, points of view that have not been considered. Students need to learn to think flexibly, and respond to new data, constraints and resources. They need to be able to work in teams, because any serious engineering problem requires a range of expertise that does not typically reside in a single individual. Often, team members, vendors and clients are widely separated in time and space; thus communication is particularly important. Sometimes communication is restricted to the Internet; while in other situations, there will be a need to explain things face-to-face. Thus, the curriculum should prepare students to convey their ideas in many ways, including written, graphic and oral formats.

ASME will be heavily involved in this effort. First the Professional Practice Curriculum modules, such as ethics, leadership, and environmental impact will be incorporated in appropriate courses. Second, ASME will offer a modified version of its Effective Teaching Workshop at CCNY to introduce new teaching strategies. (For more detail, see Section 7, Collaboration with ASME)

c) Preparing the emerging workforce for industry needs: recruitment and retention

A study was undertaken to get a picture of the academic progress of our ME students. It involved seven cohorts of a total of 97 students (85.9% men and 14.1% women), who were admitted between February 1997 and February of 1999. The group included forty-seven transfer students, with the majority from CUNY sister institutions. The study tracked four categories of students: (1) students who graduated, (2) students likely to complete their studies, (3) students unlikely to complete their studies, and (4) students who dropped out.

Term-by-term academic results were tabulated for all students from their arrival at CCNY until the end of the Fall term of 2002. Thus, the earliest and latest incoming cohorts could be observed for six and four years, respectively. Our study revealed two categories of successful students. One group reaches graduation after an average time of 4.8 years, the other takes an average of 6.3 years. Together these two groups furnish a retention rate of just above 60%. We intend to explore new ways to reduce the time to graduation by the second group. Special advisement by the department on student loan and scholarships will be introduced.

Analysis of other retention/graduation data (Spring 1997 to Fall 2002) showed that: (1) the retention rate of minority students (African-American and Hispanic) lags behind that of non-minority (white and Asian) students by 15%. (2) most students who drop out of mechanical engineering do so just after the first year.

Four key factors position CCNY favorably to dramatically increase the number of engineering graduates: (1) It is a publicly supported university with relatively low tuition; (2) It is associated with six community colleges and a technical college that are also members of the 21-campus CUNY system; (3) It draws students from a huge reservoir of foreign born and first generation US citizens who, for economic and cultural reasons, favor engineering as a career and (4) It currently has a large pool of Hispanic and African-American students and has the potential for impacting an even larger number of such students.

A. Recruitment

For the aforementioned reasons, significant increases of women and Hispanic students can be achieved. Hispanic culture has high regard for engineering. In addition the recently observed drop in the enrolment of African Americans needs to be reversed. The Office of Student Programs (OSP), led by Assistant Dean Brown, will assume a pivotal role in our recruitment effort. Various types of design contests and workshops will be used in our recruiting strategies.

The Role of Design Contests

Our department has been very active in participating in regional and national design competitions. For over two decades we have been a major force in the ASME regional design contests. More recently our students began to participate in the AIAA airplane design and SAE Mini-Baja car competitions. The excitement, interest and pride generated by these contests are impressive. They satisfy the need to invent, design, build, test and win. We plan to use design projects as a recruiting and retention tool in three proposed programs.

The Freshmen/High School Design Contest: We propose to offer a Freshmen/High School design contest involving several simple design problems. Students will work in teams of two: CCNY and high school. To use this as a recruiting mechanism each freshman will be encouraged to work with a qualified high school friend. Participants will be offered certificates and winners will be given awards and scholarships.

The ASME, SAE and AIAA Design Contests: To encourage participation in the annual ASME, SAE and AIAA design contests, the ME Department offers an elective course based on these projects. We believe that one of the most effective approaches to attracting community college students to pursue engineering as a career is to involve them in annual design contests. We propose to enroll interested candidates as members of ASME, SAE or AIAA. Membership will not only entitle students to participate in the contests but also involve them in the life of our student chapters. Community college students will be enrolled in the elective course with other CCNY students. Each community college student will be teamed up with two CCNY students. Team work builds friendship and promotes collaborative learning.

Reverse Engineering Workshop: “How Does it Work and How Was it Made?”: We are planning a one week summer workshop for high school students. Each high school student will be teamed up with a CCNY student. Each day, teams will be given a functioning familiar device such as a hair dryer, mixer, small pump, aspirator, CPAP breathing machine, etc. A short introduction will be given by the instructor on how to disassemble the device and what to look for. Teams will be asked to disassemble and reassemble the device. Each team will prepare a short report on the strengths and weaknesses of the existing design and what change they would make if they were to redesign it. At the end of the workshop certificates will be given to all participants. Awards and scholarships will be offered to winning teams.

B. Retention

The School of engineering already has successful programs aimed at retention. In 1987, under the leadership of Assistant Dean Brown, the Office of Student Programs (OSP) launched the Program for the Retention of Engineering Students (PRES). It offers a comprehensive array of academic support services, programs, and activities to enhance student retention, improve the academic performance, and enhance the career potential of engineering students. In addition to expanding the activities of (OSP) we propose the following measures:

Taking account of the experiences of women: Female students and faculty play a major role in the Department. Women are consistently well represented among the academic award winners, and leaders of the student organizations, and women are often sought by male students as group members and team leaders,

because the superior quality of their work is well known. Three of the seven most recent faculty hires have been women, and all three are highly respected as teachers and research mentors. At the same time, women as a group continue to be underrepresented, constituting about less than 15% of the student body. It is therefore important to understand and respond to the experiences of female students, with a goal of increasing their participation in the Department and the field of mechanical engineering. Towards these ends, we plan to convene regular focus group meetings to explore the problem of underrepresentation of women, and develop strategies to address this issue. These meetings will include male and female faculty and students, and will be attended by the PI and co-PI's. The outcomes of these discussions will be used to inform the entire curriculum reform effort, including introduction of new pedagogies and emerging technologies, as well as activities more specifically targeted at recruitment and retention.

Early Exposure to Engineering: A significant number of students who enroll in engineering as freshmen change their major or drop out. Engineering students are often disappointed to find that most of their study in the first two years consists of basic science and mathematics. Exposing them to engineering projects early satisfies their interest in practical matters relating to how things work and how they are made. Participation in our three design contest programs described above is intended to answer this need.

Early Intervention with Marginal Students: Experienced instructors can identify students who are likely to fail a course very early in the semester. Often the problem has to do with attitude rather than ability. A procedure will be put in place for faculty to meet with these students in a friendly and supportive atmosphere, offer advice, guidance and help.

4. MODIFICATION OF COURSES

In this section we present in tabular form (see Table. 1) the comprehensive changes that will be introduced in the courses offered by the department. In the first column we give the course number and title. In the second and third column we present the emerging technologies/elimination of legacy material, and the new teaching strategies that will be incorporated into each course. For current description of each course please refer to the department's website www-me.cuny.cuny.edu. The mathematics and science courses are not included in the table. These courses common to all engineering disciplines are also under continuous review for modification in line with the ideas advanced in this proposal. Some newly developed elective courses are also omitted.

In the next section, the modification of two existing courses, Heat Transfer and Engineering Materials and the content of one new course Micro/Nano Materials and Manufacturing will be presented in more detail to highlight the reform effort and how courses will look after modification.

Table 1. Modifications introduced in ME courses

| | Course number and title | Incorporation of emerging technologies / <i>Elimination of legacy material</i> | Introduction of new teaching strategies |
|------------------|---|---|---|
| Required Courses | ME 145 Computer-Aided Drafting | — | Disassemble a real product; construct drawings of it; group poster presentation |
| | ME 246 Engineering Mechanics I (Statics) | Introduce forces in small structures; add biological examples; introduce software for calculations of trusses and frames <i>Minimize hand computations</i> | Assign individual and team projects involving analysis, computer simulation and design. |
| | ME 247 Engineering Mechanics II (Dynamics) | Introduce new software to simulate motion of particles and mechanisms (Working Model) <i>Eliminate graphical methods of calculating velocities and accelerations</i> | Cooperative learning: in class and homework assignments; project-based learning: mechanism analysis and design using simulation software; home experiments. |
| | ME 330 Mechanics of Materials | Introduce software; introduce examples from MEMS, biological systems; introduce advanced materials, composites <i>Eliminate some methods related to deflection of beams; eliminate Mohr's circle</i> | Add laboratory component (demonstration of force, torque and strain measurements); Assign home experiments. |

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| Required Courses | ME 322 Computer Methods in Engineering | Replace current project with a modular project involving applications inspired by micro- and nano technologies | Interdisciplinary Modular Project: assign each group a piece of a large project; groups report outcomes and demonstrate how they fit in the overall problem. |
| | ENGR 230 Thermodynamics I | Application of thermodynamics cycles to new energy conversion technologies and biological systems; introduce statistical thermo-dynamics and relation of observed properties to molecular behavior | Assign home experiments |
| | ME 311 Mechatronics | Incorporate microsensors and actuators using MEMS technology and advanced materials. | Cooperative learning: students will solve problems in class and collect and analyze data; project-based learning: students perform computer simulation and analysis and conduct literature searches; laboratory experience: students already conduct experiments and collect and analyze data |
| | ME 356 Fluid Mechanics | Introduce molecular basis of fluid phenomena, flow visualization software (FLUENT) | Home experiments |
| | ME 331 Thermodynamics II | This course will be combined with ME 471 (Energy Systems Design) to form a new course, ME 431 (Thermal Systems Design and Analysis) | |
| | ME 461 Engineering Materials | The changes in this course are highlighted in detail in the next section | |
| | ME 371 Computer Aided Design | Add a micro/nano/bio related project; design for manufacturability; consider effect of scale on tolerances and fabrication; increase emphasis on finite element modeling (FEM) | Group projects and presentations. |
| | ME 421 Systems Modeling Analysis and Control | This course has been recently updated to include use of software interdisciplinary topics and laboratory experiences. | Course already incorporates new teaching strategies. |
| | ME 433 Heat Transfer | The changes in this course are highlighted in detail in the next section | |
| | ME 471 Energy Systems Design | This course is being combined with ME 331 (Thermodynamics II) into a new course ME 431 (Energy Systems Design). For details see section 6 of this proposal | |
| | ME 472 Mechanical Systems Design | Expose students to microscale design considerations for MEMS machine elements <i>Reduce coverage of brakes, clutches, shafts and gears.</i> | Require students to reverse engineer and then reengineer some device employing a combination of common machine elements. |
| | ME 436 Aero-Thermal-Fluid Lab | Add new microscale fluid flow and heat transfer experiments. Examples: micro-nozzles, micro-heat exchangers and micro-scale heat pipes <i>Eliminate refrigeration cycle experiment</i> | Design of an experiment; group presentations. |
| | ME 462 Manufacturing Processes | Introduce microfabrication processes and thermal and packaging issues related to microelectronic devices; introduce manufacturing methods specific to MEMS, such as micromachining; <i>Reduce coverage of traditional machining and metal forming</i> | Course already incorporates new teaching methodologies such as cooperative learning, project-based learning, and teaching experiences for undergraduates (use of student lab facilitators) |
| | ME 473/474 Senior Design Project | Assign projects involving biotechnology, MEMS and nanotechnology in collaboration with industrial partners. | Courses incorporate cooperative and project-based learning, group presentations and hands-on experiences; incorporate modules developed by ASME regarding professionalism, ethics, and others. |

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|------------------|---|--|--|
| Elective Courses | ME 441 Advanced Stress Analysis | More emphasis on thermal stresses, with examples from MEMS and electronic packaging; emphasis on thin films, residual stresses; software modeling. <i>Eliminate: Bending of curved beams; torsion of non-circular cross-sections</i> | Projects including analysis, simulation and design. |
| | ME 511 Advanced Mechatronics | Incorporate Intelligent Systems | Course already incorporates cooperative learning, project-based learning, research, lab experience, and interdisciplinary learning |
| | ME 537 Turbomachinery | Introduce advanced high temperature materials for gas turbines, including potential offered by coatings; introduce advanced combustion control technology, use of software tools and advanced hybrid cycles <i>Reduce material on steam turbines</i> | Laboratory demonstrations |
| | ME 539 Internal Combustion Engines | Change name to Automotive Engines. Include consideration of new energy conversion technologies, such as: fuel cells, electric, hybrid; alternate fuels; new cycles; pollution control; <i>Eliminate: carburetors. Substantially reduce coverage of conventional IC engines.</i> | |
| | ME 542 Introduction to Theory and Practice of Vibration | Introduce smart structures, vibration control, active damping and noise reduction; <i>Reduce mathematical background material already covered in other courses</i> | Assign a research project on current applications |
| | ME 546 Robotics and Automation | Incorporate material about robots for space exploration, remotely performed surgery and microrobots for medical applications. <i>Deemphasize conventional industrial applications such as welding, spray painting.</i> | The course already uses project-based cooperative learning approach |
| | ME 547 Environmental Control | Introduce renewable energy sources and commercial HVAC CAE software to <i>reduce dependence on conventional calculation methods.</i> | Introduce Interdisciplinary Modular Project: assign each group a piece of a large project; groups report outcomes and demonstrate how they fit in the overall problem. |
| | ME 548 Aerostructures | Include advanced materials, sensors, and use of specialized software; <i>Reduce: review and deflection analysis</i> | This is a project -based course; require oral presentation of projects |
| | ME 556 Advanced Fluid Mechanics | Add topics in biofluidics and introduce computational fluid dynamics software (CFD) | Projects using CFD |
| | ME 571 Mechanism Design | Introduce mechanism design software packages and miniaturized mechanisms. <i>Eliminate graphical approaches. reduce conventional linkage analysis.</i> | Reverse engineer, then reengineer some tangible mechanisms such as printers and copiers |
| | ME 572 Aerodynamic Design | Add materials in MEMS, adaptive materials, and actuators | This is already a project based course |
| | ME 526 Finite Element Method | Introduce interaction problems, e.g. fluid mechanics coupled with solid mechanics or heat conduction coupled with stress analysis; introduce applications related to advanced materials (e.g. composites) and MEMS. <i>Reduce material related to matrix reduction and equation solvers</i> | Assign related projects |
| | ME 536 Energy Conversion | Introduce new alternative energy sources, hybrid systems (e.g. solar/wind). | Visits to related industries |

5. HIGHLIGHTED COURSES

a) ME. 461: Engineering Materials

The existing course provides both a materials science background, and a survey of the major categories of engineering materials, including their properties and applications. The course already includes many of the pedagogical strategies identified in this proposal: cooperative learning, project-based learning, research methods, laboratory experience, and independent learning; and addresses all three of the common themes: critical thinking, teamwork, presentation skills. However, it does not include significant interdisciplinary experiences, nor do students engage in hands-on laboratory experiments. Furthermore, little attention is directed towards emerging technologies, except as optional topics for the final project. The proposed changes would correct both kinds of deficiencies.

The major pedagogical innovation would be to provide hands-on experiences in the use of materials testing equipment. Currently, the experiments are conducted as demonstrations, with students analyzing data that is supplied by the instructor. Except for the experiments involving use of a furnace, all experiments would be shifted into a hands-on environment, with students collecting and analyzing their own data. These experiments would include: tensile tests of metals and polymers, including use of the environmental chamber for temperature-dependent testing; three-point bending of metal and glass specimens to investigate low-strain rate fracture phenomena; macro- and microhardness tests, including use of image processing software to measure indentation length; and metallography, using both optical microscopy and a computerized image analysis to acquire phase statistics, grain size and grain orientation data. In addition, compression tests of concrete would be included.

Technical support for these experiences will be provided partially by undergraduate student facilitators, who had taken the course previously. They will receive credit through the new Undergraduate Teaching Experiences elective.

There are several examples of emerging materials that could naturally be introduced into the course. These include: shape memory alloys; nanograin materials, carbon nanotubes, nanoparticle and nano-fiber-reinforced composites. In addition, topics will be added on electrical, optical, magnetic, and chemical properties of materials, including corrosion. These topics are justified by the importance of these properties as limiting factors in many current applications, and will replace legacy materials on heat treatment of metals and traditional ceramics. Finally, to emphasize the importance of new developments in engineering materials, the existing Final Project assignment would include topics related to emerging technologies.

To accommodate these modifications one additional contact hour will be added to this course.

b) ME-433 Heat Transfer

Heat Transfer is a required course covering conduction, convection and radiation. In addition to grounding students in the fundamentals of heat transfer, our objective in revising this course is to broaden the student's perspective of the subject and emphasize non-traditional pedagogical strategies. We plan to go beyond conventional topics by including applications to melting and freezing, cryosurgical probes, food refrigeration, heat transfer in living tissue such as the human arm, rat tail, dinosaur armor, elephant ear. A chapter on microscale heat transfer will begin with the limitations of the macroscale model and describe the microscale approach. Software codes will be developed and used to construct microscale solutions to problems in conduction, convection and radiation. Results will be compared with macroscale solutions. The new material will be covered in eight lectures. An equal number of lectures on topics that are not critical to understanding the fundamentals of heat transfer will be deleted. These include two-dimensional conduction, one-dimensional transient solutions, derivation of the Navier-Stokes equations, Blasius problem, Pohlhausen's solution and multi-surface radiation interchange.

Several of the pedagogical strategies articulated in this proposal have already been incorporated in this course. These include cooperative learning, project-based learning and laboratory experience. The added material on heat transfer in living tissue and microscale heat transfer will introduce interdisciplinary learning.

In addition to weekly homework problems, students work on design projects and computer assisted problems. A unique aspect of this course is the four crude experiments students perform at home with family members or classmates. Two new experiments will be added in the revised course. To exploit the benefits of cooperative learning alternate weekly assignments will be done in teams of twos.

c) ME-463 Micro/Nano Materials and Manufacturing (New Course)

Core Curriculum Junior-Level Course (3 Credits; 3-hr lecture, 1-hr lab)

The aim of this course is to introduce students with diverse technical interests to the area of micro- and nanoscale phenomena in science and engineering. The course will highlight the specific qualities of: (i) *Material Properties and Strength*; (ii) *Fluid and Thermal Transport*; and (iii) *Manufacturing Techniques*. Discussion of material properties will include contact mechanics, elasticity, and mechanics of fracture. We will discuss the properties that emerge at the micro- and nanoscale, such as the change in deformation processes from continuum to discrete, and the increase in stored energy due to increased surface area to volume ratio. The course will also discuss how the large fraction of interface ions in micro- and nanomaterials increases their strength and adhesion, and alters their molecular forces and vibration behavior. Students will work in groups during the laboratory exercises to conventionally test macroscale properties and then compare these values with their microscale counterparts.

In the area of fluidics, the course will emphasize the increased importance of surface roughness, surface tension, frictional losses and flow fluctuations. For instance, when confined to tight spaces, long-chain lubricant molecules act more like soft solids, and form ordered layers that influence the movement of sliding surfaces. Further, confined fluids composed of molecular mixtures segregate themselves by size, with the longer chain molecules adsorbing near the surfaces and the smaller ones remaining in the middle region of the confining gap. From the thermal perspective, the extremely small heat dissipation of nanomaterials modifies their thermal transport and thermal conductance at interfaces, as well as their material properties and surrounding micro-thermal-environment. Students will work on projects that evaluate the thermal and fluidic properties of micro- and nanoscale devices and then propose possible improvements to these designs.

Lastly, the manufacturing portion of the course will address microfabrication techniques and their applications to three-dimensional structures and systems with micrometer dimensions and smaller. The course will emphasize classical fabrication methods such as photolithography and micromachining, as well as new techniques involving self-assembled-monolayers. This portion of the course will be centered upon a series of investigative exercises including microfluidics experiments, electro-mechanical testing of microdevices, and manipulation of carbon nanotubes. As a final project, students will work in groups to design a micro- or nanosystem for a specified application and then use the CCNY microfabrication laboratory to manufacture it. Course material will also discuss the evolution of select micro/nano innovations and their impact and applications in applied sciences, medicine, space development, policy, and the environment.

6. ELIMINATION AND ADDITION OF COURSES-NEW SCIENCE REQUIREMENTS

The curriculum reform effort will include the elimination of an existing course, inclusion of a new one, and also changes in the elective offerings and requirements. These changes have been recommended unanimously by the Department Curriculum Committee, and endorsed in principle by the entire Department.

The new required course will be ME 463, Micro/Nano Materials and Manufacturing. This course is described in detail above. In order to make room for this course, without affecting the total credit requirement, two existing courses will be replaced by one, thereby eliminating legacy materials that are of less relevance to current technology. The courses to be eliminated are ME 331: Thermodynamics II, and ME 471: Energy Systems Design. The latter course deals primarily with conventional power plants and steam generators. The new course, ME 431: Thermal Systems Design and Analysis will include salient features of both courses, except that the use of computerized steam and gas tables would be incorporated into the first Thermodynamics course. Also some of the material will be covered in ME536, Energy Conversion.

There will be significant changes in the elective requirements and offerings. Currently two science electives are required, in the second and fourth semesters respectively, with considerable freedom in each case. Students are permitted such options as astronomy, environmental geology, ecology, and earth systems science. A narrower list will better provide the background needed for the subsequent study of emerging technologies. Therefore, the proposed change will restrict the second science elective to one of only three courses: Human Physiology, Organic Chemistry, or Modern Physics. This change will provide a firmer foundation for further study in biotechnology, polymer engineering, and micro/nano technology, respectively. Finally, a new elective course is proposed that will grant credit for undergraduate research or teaching experiences. To provide consistency, all faculty who serve as mentors will meet to determine a common structure and set of course requirements.

7. COLLABORATION WITH ASME

The curriculum reform effort will be carried out in partnership with the American Society of Mechanical Engineers (ASME) (see ASME letter of support). The collaboration with ASME will be in the four areas described below.

- a) *Incorporation of ASME Professional Practice Curriculum modules into the ME curriculum.* The ASME is currently developing online educational modules related to the practice of mechanical engineering. These modules deal with issues such as ethics, leadership, project management, product life-cycle management, environmental impact, entrepreneurship, and others. Ten of these modules have already been developed towards a goal of developing 40. Some of these modules are being incorporated into our senior design course and as more become available they will be considered for incorporation. The department will provide feedback to ASME through a survey that the students can fill out on line. ASME will use the student feedback for improvement of the modules.
- b) *Effective Teaching Workshop:* ASME currently offers effective teaching workshops at various locations that college instructors and others can attend. During each of the three years of the proposed grant the ASME will conduct special versions of the workshop at CCNY that faculty, adjuncts and others can attend. This will be helpful in introducing new teaching strategies to the instructors. Participants will provide feedback to ASME.
- c) *Industry Advisory Board:* ASME will form an industrial advisory board independent from the ME department to provide input and feedback about the curriculum reform effort. The advisory board will be convened by ASME once a year face-to-face and several times a year through teleconferencing. The department will present its reform plan and the implementation activities to the advisory board for comments and suggestions. The feedback will be used to modify the plan and adjust the implementation as warranted.
- d) *Dissemination:* Since ASME has unrivaled access to the mechanical engineering community and strong ties to other engineering organizations, it will undertake a major effort to publicize the reform effort and its results. First, ASME will publicize the progress of the CCNY reform effort on its mechanical engineering department heads' website and other ME education sites. Results will be further disseminated employing ASME listservs and its database of approximately 6,000 members for whose primary job function is education. It will also organize a session devoted for presentation of the reform results both at the Annual ASME Congress and Exposition and the Annual ASME Mechanical Engineering Education Conference. During these sessions representatives from the CCNY ME department and ASME will present the reform strategy, available results, discuss the structure and process of conducting the reform and will solicit comments and ideas from the broader ME community. ASME will also disseminate the results beyond the ME education community through the engineering deans. Mailing lists will be rented, and a postcard will be mailed to each engineering dean to draw attention to the project website. A similar strategy will be used to reach the 10,000 members of ASEE.
- e) *Engagement:* ASME will receive a project subcontract from CCNY to underwrite these activities.

8. IMPLEMENTATION AND MANAGEMENT PLAN

The PI, Prof. F. Delale, Chair of Mechanical Engineering will be in overall charge of the project. Since there

are three distinct elements of the reform effort, namely incorporation of emerging technologies, introduction of new teaching strategies and recruitment and retention, the three CO-PI's from CCNY (Profs. J. Hammonds, G. Beneson and L. Jiji) will be each responsible for one area. The Co-PI from ASME Mr. T. Perry will be in charge of the ASME activities. The Assoc. Dean for Undergraduate Affairs A. Walser will ensure compliance with ABET guidelines. Prof. D. Coates of the CUNY Graduate Center will be the project evaluator. The PI and Co-PI's will act as an executive committee and will meet monthly to review progress and insure that the project is implemented according to plan. They will also decide on the compensation of participating faculty and major expenditures. Emeritus Prof. G. Lowen, former department chair, will serve as part-time administrator. He will also participate in recruitment and retention efforts. Prof. Jiji will coordinate recruitment and retention efforts with Assistant Dean Brown, Director of OSP.

The PI will review the progress of the project with the faculty in monthly departmental meetings and will call special meetings dedicated to the discussion of the project. The entire Department will be engaged in implementation, as in the planning process. The organizational chart of the project is given in Fig 1.

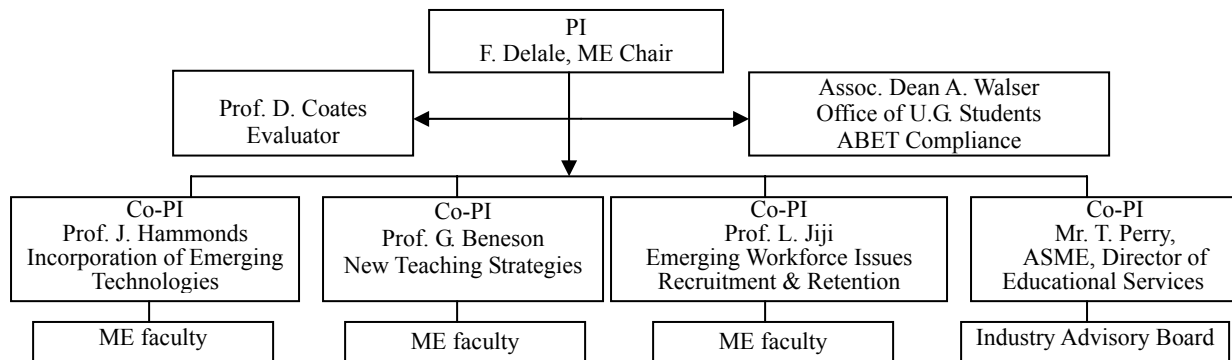


Fig 1. Organizational Chart

The project will be implemented according to the following timeline:

January 1, 2004 - August, 2004: Refinement of reform plan, organization of Industry Advisory Board, obtaining necessary College and University approvals for changes in the curriculum, procurement of new equipment and software for new or existing laboratories, preparation of assessment instruments

September, 2004 – May, 2005: Implementation of reform in Freshman and Sophomore year courses; implementation of recruitment and retention efforts; feedback from Industry Advisory Board; establishment of new labs and lab modifications; assessment

June, 2005 – August 2005: Study feedback from stakeholders; adjustments to plan based on feedback and assessment; recruitment

September, 2005 – May, 2006: Implementation of reform in Junior and Senior year courses; feedback from industrial partners through ASME; recruitment and retention efforts; assessment; dissemination

June, 2006 – December, 2006: Additional feedback from ASME; assessment, and dissemination of results

9. ASSESSMENT PLAN

The proposed project is best served by an implementation assessment approach to evaluation. It is essential to determine whether or not a program has actually been implemented before outcomes can be achieved or assessed over time. The ME Department at CCNY proposes a major curriculum reform and will need to know whether or not the reform is actually in place. The approach outlined is based on best practices described by leading evaluation experts (King, Morris, & Fitz-Gibbon, 1987; Lipsey & Cordray, 2000; Scheirer, 1994). There will be focus on collecting and reviewing existing data to determine to what extent the proposed changes are being achieved. These data will help the ME Department to be accountable for producing the intended effects described in the proposal.

A second reason for assessing program implementation is that it provides objective interpretations of the program's achievements. Faculty and administrators will be able to use these data to revise program

components in the later stages of the program. It will provide on-going and objective feedback on the curricular changes that are proposed. An outline of the implementation assessment plan for the activities proposed here appears in Table 2.

Table 2. Implementation Assessment Approach to Evaluating the CCNY ME Curriculum Reform Project

| Program Component Briefly Described | Implementation Assessment Activities and Measurement Approaches | Timeline |
|--|--|---|
| N/A | 1. Development of program objectives and refinement of implementation evaluation plan. | January – April '04 |
| N/A | 2. Development of implementation assessment scales and approaches. | May – August '04 |
| Incorporating emerging technologies into curriculum | 1. Content analysis protocol for review of specific curricula elements such as MEMS, CAE, etc. in course materials. 2. Interviews with key project leaders re: equipment, software, lab preparation, etc. | July – August '04 |
| New teaching methodologies | 1. A pilot study will be developed to compare the effectiveness of some of the new teaching methods within a semester course. Outcomes will be determined using student and faculty interviews and surveys. | Sept. – May '04-05 and Sept-May '05-'06 |
| Emerging workforce: Recruitment | 1. Staff and student surveys and focus groups. (Women students will be oversampled.) 2. Content analysis and record review for ME project 3. Workshop evaluation scales | Sept. – May '04-05 and Sept-May '05-'06 |
| Retention | (As above and...) 4. Review and analysis of retention data | Sept. – May '04-05 and Sept-May '05-'06 |
| Course modification | 1. Content analysis of course materials procedures using expert external reviewers from other engineering programs (To be recruited with assistance and approval of ME key leaders). | Sept. – May '04-05 and Sept-May '05-'06 |
| Changing science requirements | 1. Review of ME records and meeting minutes; interviews with key ME leaders and ASME leaders (e.g. industry representatives). | Sept. – May '04-05 and Sept-May '05-'06 |
| ASME collaboration | Interviews with key participants at ASME and CCNY about the collaborative process | April '04 and '05 |
| N/A | Preliminary feedback report submitted | June '05 |
| N/A | Final analysis of ME Curriculum Reform approach | May – July '06 |
| N/A | Review of implementation findings with ME team | July '06 |
| N/A | Preparation of final report and submission | August – December '06 |

10. DISSEMINATION

As explained earlier a major component of the collaboration with ASME concerns dissemination. This effort was described in Section 7, under Dissemination. In addition, the results of the project will be disseminated in several ways. These include: a) presentations and publications in professional conferences and journals b) a dedicated CCNY website containing transportable teaching modules for downloading c) regional and national workshops for other engineering departments.