

The Story of the Gateway Engineering Education Coalition Project at Columbia

A Decade of Innovative Changes: 1992 – 2002

Introduction

As the 21st century begins, we are witnessing and participating in an era of historic change in higher education fostered and enabled by stunning developments in digital technology and the cognitive sciences. Revolutionary changes in scholarly and scientific communications created largely by engineering achievements in computers and communications are affecting the way institutions conduct their academic missions of education and research at the frontiers of knowledge. Institutions are being compelled to respond to rapidly changing national and global environments driven by technological innovation, competition and economic necessity. The challenges are unprecedented but they reflect revolutionary changes that are transforming business, governance and academia nation-wide.

While these developments are impacting every corner of higher education, they are particularly noticeable in undergraduate engineering education which has been criticized in the past for adhering to an outdated educational philosophy and curricula established more than four decades ago when the space age began. The curricula in place in the first half of the decade of the 1990's were slow to acknowledge the explosive growth of information and automation in the classical engineering disciplines such as civil and mechanical engineering, the need for new disciplines such as biomedical engineering and earth and environmental engineering, and the need to adapt newly developed methods of pedagogy. The pervasive role of the computer has dramatically altered the engineering landscape. The tools and practice of engineering are changing at a rapid rate, on a scale and in ways not previously experienced. At the same time major demographic changes are influencing the composition of the student body being attracted

to engineering study. These developments make it essential that educational institutions seek to endow students with the kind of knowledge and tools that will empower them to work in evolving and yet to be invented interdisciplinary modes and to provide an education which will serve a diverse student body while encouraging a desire for life-long learning.

As a consequence, a new vision of engineering education is taking form which, among other paradigms, emphasizes the development of students as emerging professionals and the need to immerse students in engineering design and practice as early and as pervasively as possible throughout the curricula, while at the same time integrating the computer into the curriculum as an intellectual and professional tool at all levels of study. The computer is an essential attendant and critical enabling tool that needs to be supplemented by such new technologies as multimedia, video conferencing and high speed networks. New forms of pedagogy and curricula are rapidly evolving as a consequence of the dramatic advances in technology and the cognitive sciences and the societal pressures to open engineering education to a more diverse student population than in the past.

NSF-Supported Coalitions:

To implement major changes institution-wide is a daunting undertaking that requires both intra- and inter-institutional collaboration on a broad front in order to provide the necessary imperative for change through competition as well as to support wide-ranging innovation and experiment with curricula, technology and methodology. Under mounting pressure from industry and the government, undergraduate engineering education rose to become a critical issue on the national education agenda in the late 1980's. The NSF and other government agencies and private foundations began to solicit proposals and provided substantial funding for a plethora of new, experimental and exploratory programs at many dozens of institutions.

One major initiative developed by the NSF for this purpose was the creation of the *Engineering Education Coalitions* program in 1990. The program was a follow-up to the first recognized and early effort to explore radical new curricula and pedagogy that

was initiated by Drexel University in 1988 with the support of a major grant from The National Science Foundation. By 1990, with the promise of Drexel's E⁴ (.....), the National Science Foundation, through its various educational advisory bodies and committees came to a similar conclusion and created a number of new initiatives that sought proposals from groups of collaborating academic institutions. The objective was to have several (5 to 10) schools join to form a coalition that would include a diverse group of institutions (public and private, large and small) that would work together and use their diversity to develop new curricula, attract minority students, develop new modes of educational delivery, etc. Over a period of 2 to 3 years, a number of such *engineering education coalitions* were formed and funded by the NSF.

The Gateway Coalition

In particular, the 10 deans of engineering at Columbia University, The Cooper Union, Ohio State University (OSU), New Jersey Institute of Technology (NJIT), Case Western Reserve University (CWRU), University of South Carolina (USC), Drexel University, University of Pennsylvania (Penn), Florida International University (FIU), Polytechnic University of New York, formed a coalition they named "Gateway", committed to revitalizing and restructuring undergraduate engineering education for the 21st century. The goal was to "open new gateways to learning" through collaboration among institutions as well as through individual institutional initiatives. The proposal was funded in early 1992 with the deans as principal investigators for this five-year project labeled *Gateway Engineering Education Coalition*, or *Gateway* for short. NSF awarded \$15 million to the coalition to for five years to be matched with funds raised by the individual institutions. The project began in March 1992 and was expected to continue until 1997. At the end of the 5 years, the Gateway Coalition was deemed successful enough for NSF to award an additional 5 years of funding at approximately the same level. Three of the original institutions, CWRU, FIU, and Penn, declined to continue as part of this second phase.

Participation in the Gateway Coalition for the past decade has thus provided Columbia a truly unique opportunity to engage in rich collaborations both within the University and with other institutions on an unprecedented scale in pursuit of a long

overdue restructuring of undergraduate engineering education. The impact of the reform has extended considerably beyond the confines of engineering at Columbia. The restructuring has stimulated campus-wide interest and the active cooperation of faculty and students in many non-engineering departments. As a result the School has developed rich interdisciplinary collaborations on a broad front within the University as well as support for wide-ranging innovation and experiment with curricula, educational technology and methodology. A number of these collaborations and innovations are described further on.

Columbia's Historic View

As one of a handful of universities that predate the American Revolution, and one of the first to establish an engineering school in the 19th century, Columbia has always had to recognize the winds of change in order to remain a preeminent institution. Its leadership role in helping to define and create the modern comprehensive research university is well-documented. Columbia has played a similar but perhaps less well-known role in engineering education. In a recent publication by a sister institution (Worcester Polytechnic University), the issue devoted to “Creating a New Vision for Technological Higher Education,” began with the following:

“Just over a century ago, at the first meeting of what is now the American Society for Engineering Education (ASEE), William Burr, professor of civil engineering at Columbia College School of Mines, gave a presentation titled “The Ideal Engineering Education.” He emphasized two fundamental characteristics he believed should be part of such an education. The first was a broad, liberal education in philosophy and the arts that would serve to cultivate human qualities and enable engineers to interact well with people, as well as with matter. The second was a thorough training in the natural philosophy of engineering, which he said included the body of mathematical and scientific knowledge constituting the theory of engineering. He believed the second feature to be as profoundly practical as it is profoundly theoretical. Burr was clearly ahead of his time. The framework he proposed is remarkably consistent with efforts underway by several prominent organizations, including ASEE itself, to reshape

engineering education. There are some additional concerns that face modern engineering educators, of course, such as the need to attract more women and underrepresented minorities to the field, the need to place more emphasis on teamwork in the engineering curriculum, and the need to stress the global context in which the engineering profession is practiced today. But Burr's fundamentals are basic elements of the plans that evolved from the work of the ASEE, the National Research Council, the National Science Foundation and other groups committed to reforming engineering education".

Professor Burr's plans were operative at Columbia and at most other institutions until the post-World War II era when university-based research became a major force in society and science began to dominate the engineering curriculum at the expense of engineering practice. As pointed out in the previous quote, the world we face now is better tuned to the kind of education envisioned by Burr almost one hundred years ago.

The Gateway Story at Columbia

This document is a brief description and history of the efforts by the School of Engineering and Applied Science to reform and restructure undergraduate engineering education at Columbia during the decade of 1992 to 2002 as part of the Gateway Coalition.

Institutional Profile: The University at Large

Columbia, founded in 1754, is the oldest institution for higher education in New York State and fifth oldest in the nation. It is a private, non-sectarian comprehensive research university located in New York City. with 15 schools, 75 academic departments, covering all of the arts and sciences and the professions of architecture, arts, business, dentistry, engineering, international affairs, journalism, law, medicine, nursing, public health, and social work.

The principal undergraduate divisions are Columbia College (liberal arts and sciences), The Fu Foundation School of Engineering and Applied Science (founded in 1864, as the School of Mines) and the School of General Studies. Beyond its schools and programs, the measure of Columbia's true breadth and depth must take into account its seventy-odd internationally recognized centers and institutions for specialized research, which study everything from human rights to molecular recognition, as well as the close affiliations it holds with Teachers and Barnard Colleges, the Julliard School, the American Museum of Natural History, and both the Jewish and Union Theological Seminaries. Columbia also maintains major off-campus facilities such as the Lamont-Doherty Earth Observatory in Palisades, N.Y.; the Nevis Laboratories in Irvington, N.Y.; and the Arden Conference Center in Harriman, N.Y. Involved in many cooperative ventures, Columbia also conducts ongoing research at such facilities as Biosphere 2 in Scottsdale, Ariz.; Brookhaven National Laboratory in Upton, N.Y.; and the NASA Goddard Institute for Space Studies located just off the Morningside campus.

There are 20,000 students (not including affiliates) with 10,500 men, 9,500 women, of whom 5,600 are undergraduate, 11,600 are graduate and professional, 2,800 are non-degree candidates. There are 2,350 full-time faculty of whom 33% are tenured.

The University occupies two major campuses in Manhattan, as well as additional special-purpose facilities throughout the area. Besides the main campus located on the Upper West Side in Morningside Heights, further uptown in Washington Heights is the Health Sciences campus. Comprising the Columbia Presbyterian Center of New York Presbyterian Hospital, administered jointly by the University and New York Presbyterian Hospital, the Health Sciences campus includes the College of Physicians and Surgeons, other health-related schools and programs, and parts of the Engineering School's multidisciplinary program in biomedical engineering.

The University's Mission

As one of the country's leading research universities, Columbia University seeks to make significant original contributions to the development of knowledge, to preserve and interpret humanity's intellectual and moral heritage, and to transmit that heritage to future generations of students. It pursues these missions through research and educational programs in a wide range of disciplines in the humanities, social sciences, the natural, biomedical and applied sciences, and various professions, and through cooperative agreements with other educational institutions, research centers and hospitals in the greater New York region, throughout the country and abroad.

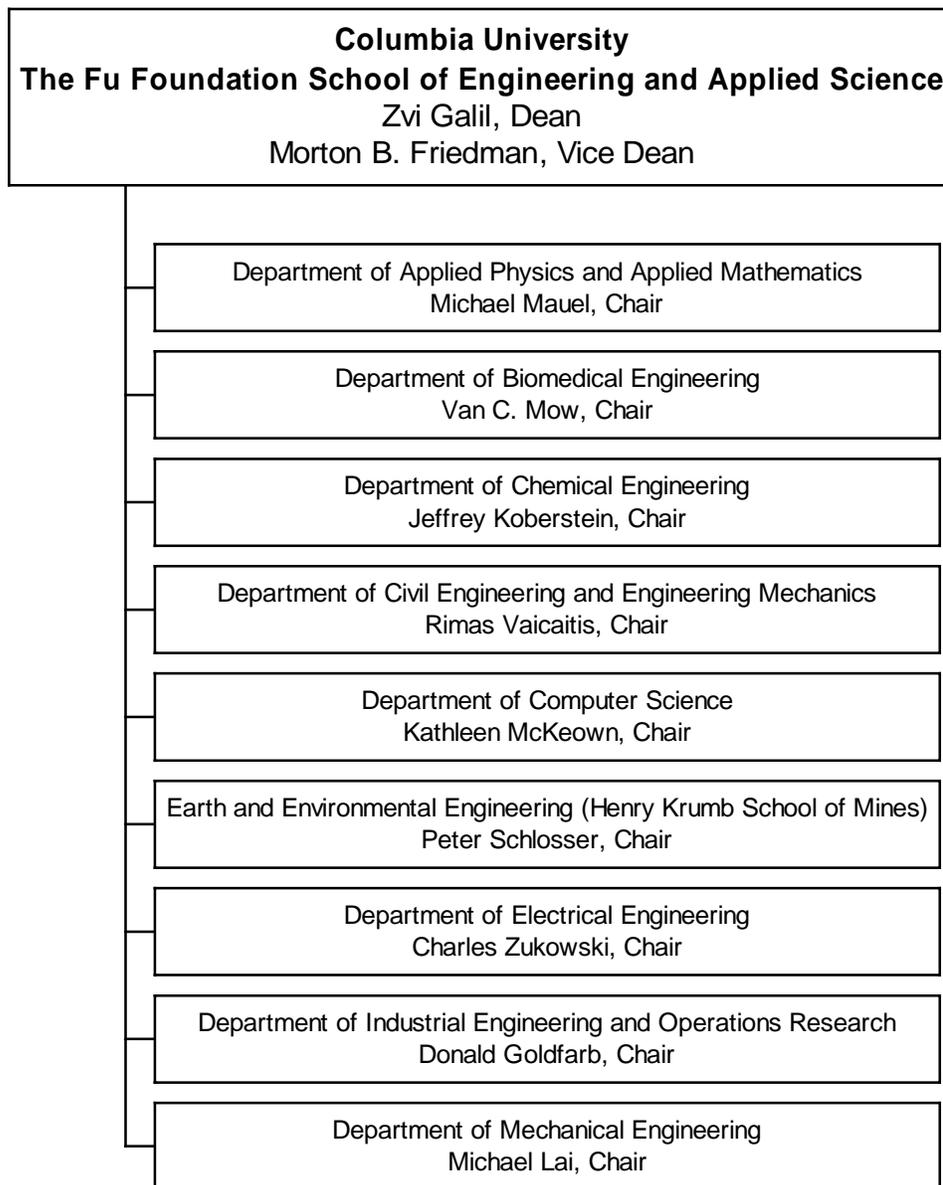
The Morningside Heights Campus

The Fu Foundation School of Engineering and Applied Science is located on Columbia's Morningside campus. The thirty-two acres of the Morningside campus comprise over sixty buildings of housing; recreation and research facilities; centers for the humanities and social and pure sciences; and professional schools in architecture, business, the fine arts, journalism, law, and other fields. The School of Engineering and Applied Science is housed in the Seeley W. Mudd Building, a fifteen story classroom and laboratory building; the Engineering Terrace Building; and the Computer Science Building. In addition, the Schapiro Center for Engineering and Physical Science Research, adjacent to the Mudd Building, houses research programs in computers, microelectronics, telecommunications, and condensed matter physics as well as a

200-seat auditorium, seminar rooms, offices, and laboratories. Other research facilities with modern equipment are available in all departments. Among the departmental facilities are laboratories for research in acoustics, artificial organs, advanced computer architecture, heat transfer, materials, lasers, nuclear measurements and technology, plasma physics, and fusion energy.

The Fu Foundation School of Engineering and Applied Science

The School of Engineering and Applied Science, is comprised of nine (9) departments. They are (as of 03/01/02)



All departments offer both undergraduate and graduate degree programs that enroll 1250 full-time undergraduates and 875 full and part-time graduate students and involve a full-time faculty of 120. Through synergy between world-class teaching and research, the School of Engineering and Applied Science strives to educate a distinguished cadre of leaders in technology and to promote faculty preeminence at the forefront of technology while being a part of Columbia University, a great intellectual and cultural center.

The Curriculum and Instructional Methodologies Prior to Gateway

In 1991 only one year before the Gateway Coalition began, the Dean of the School of Engineering and Applied Science had commissioned a faculty-student-alumni committee to review the undergraduate curriculum. The committee recommended very few changes to a curriculum that had remained relatively stagnant for three decades! This was a traditional engineering curriculum based upon a common freshman/sophomore program for all engineering students given over almost completely to conventional courses in mathematics, physics, and chemistry, supplemented by a core program in the humanities. The relevant non-engineering departments taught these courses as they had been taught for many years. Except for such services there was little interaction between engineering and other components of the University at the instructional level. The courses were presented almost totally in the conventional lecture-blackboard mode of instruction and the computer played no role in the instruction.

Thus engineering students were literally isolated for the first two years from the engineering faculty who were given no opportunity to expose the students to the excitement and practice of the profession. The lack of contact with engineering discouraged many first and second year students from remaining in engineering and turned the faculty away from interest in the first and perhaps most formative years of the curriculum. This disinterest was compounded by stringent upper division (junior/senior year) curricula in each of the several engineering fields that were largely discipline driven

with little room in their programs for enrichment or expansion into interdisciplinary and non-technical directions. Thus engineering disciplines and their technologies were jammed into the upper division of the curriculum creating a technology vacuum in the first two years. Such contemporary pedagogical notions as student-centered learning, collaborative learning, team teaching, design across the curriculum, multidisciplinary courses, assessment and evaluation of courses and programs were absent, as were the rapidly evolving new practices in the engineering world such as rapid prototyping, concurrent engineering and continuous quality improvement.

The Curriculum and Instructional Methodologies Since Gateway

Motivated by the school's involvement one year later in the Gateway Coalition and the rapidly changing educational and industrial-economic environment that was rendering the curriculum and instructional methodologies outdated, the Dean sought support for change in the early years of the Coalition. He established a school-wide planning committee charged with developing a strategic plan for engineering education and research at Columbia for the next decade. Columbia's representative on the Governing Board of Gateway was a member of the committee that drafted a formal "Strategic Plan"; Gateway's vision and initial experiences weighed heavily in the proposed reform of the undergraduate curriculum. The document affirmed the need to take advantage of new modes of instructional technology and to explore new teaching and learning methodologies to implement reform. Equally stressed in the report was the importance of close cooperation with the science and humanities faculties on course content and pedagogy in modifying existing courses and in developing new offerings as the school explores a more integrated engineering curriculum. The involvement of faculty from Mathematics, Physics, Chemistry, and the liberal arts in the process was essential to help change the institutional culture in ways that encourage the prospects for further reforms on an institutional basis. The strategic plan was the subject of an engineering faculty symposium in which the general nature of the reform received strong support.

As a follow-up, the chairs of the engineering departments, in their role as an Executive Committee for the school, moved to pursue the recommendations of the strategic plan. They appointed a “Scope Committee” charged with developing detailed proposals for implementing major curricula changes at all levels in collaboration with the engineering departments. [The chair of the Committee was the institutional activities leader at Columbia for Gateway.]

The work of the Scope Committee induced the science departments, Mathematics, Chemistry and Physics, to develop major changes in the nature and structure of their basic course offerings particularly as they impact on the engineering curriculum. These departments, in collaboration with the Scope Committee, proposed deep curricula changes that began in the fall of 1995. The effect has been to open-up the freshman/sophomore curriculum in engineering. The changes provided for the first time opportunities to introduce engineering courses and projects in the first two years and offering greater options for the upper level engineering programs. The Scope Committee presented a number of proposals for reform, which were approved by the engineering faculty in the spring of 1995. Substantial elements of the recommendations for curricula restructuring began to be implemented in the fall of 1996.

The material below describes the important changes that have been implemented at Columbia during the five years of Phase I of Gateway activities. All of the Gateway projects that Columbia faculty and students were engaged in, alone and in collaboration with other Gateway institutions or utilizing Gateway developed technologies and methodologies, have played a role in achieving the reforms described below. With the exception of a few special multimedia courses assessed as part of a Gateway project, there has been no attempt to do program or curricular assessments in these first five years.

Under the impetus of the Gateway project, the School embarked on a radical restructuring of its undergraduate engineering curricula and in the process has had a notable impact on the University. The project has addressed the need to deal with the explosive growth of information and automation in the traditional disciplines and the creation of new interdisciplinary academic and industrial milieus, the compelling need to integrate the computer into the curriculum as an intellectual and professional tool at all

levels of study and the societal need to attract and retain a more diverse student population than in the past.

Two dominant and closely linked themes characterized the efforts at restructuring:

- emphasizing “engineering -up-front” – wherein engineering and some of its functional core are introduced in the first two years and sustained throughout the four years of undergraduate education. This has been achieved by providing engineering courses, including design concepts, early in the curriculum in the lower division (freshman/sophomore years).
- creation of “learning environments” which place the student at the center to induce more prospective students to study engineering by providing a more interesting and exciting curriculum of study.

The goals are:

- exploit new scientific insight into the learning process,
- attract a more diverse student population than in the past and deal with the changing preparation and composition of the student population
- deal with the explosive growth of information and automation in the traditional disciplines and the creation of new interdisciplinary academic and industrial milieus,
- integrate the computer into the curriculum as an intellectual and professional tool at all levels of study.
- encourage undergraduate project experiences in the freshman and sophomore years
- provide more program flexibility to expand career choices ranging from “managing technology” to engaging in “leading-edge technology research”.
- give serious attention to technology as a human enterprise with enormous societal implications, through the development of courses on the nature and history of technology in cooperative or joint ventures with other components of the University.

- broaden the intellectual scope and reach of engineering education and infuse non-technical learning throughout the undergraduate years.

Serious educational reform requires deep changes in an institution's "culture". Cultural changes are particularly difficult to induce at a comprehensive research university like Columbia where the intellectual dominance of research /graduate education and the dependence of the engineering curriculum on a wide range of disciplines and departments, inside and outside the engineering school, are among the realities that must be dealt with. There has been for decades a common freshman/sophomore program for all engineering students at Columbia, as at many other institutions, given over completely to traditional courses in the calculus, physics, and chemistry, supplemented by a core program in the humanities. A positive consequence has been that engineering students are offered access to a rich and exceptionally broad range of intellectual activities in the arts and sciences. In the present curriculum all the engineering disciplines and their technologies are concentrated in the upper division (junior/senior years) creating a technology vacuum in the first two years while the engineering courses are jammed into the upper two years of the program. The result has been a fractured discipline driven curriculum with little room for science or mathematics enrichments or for expansion in new technical directions. This has been abetted by a historical reluctance to invade the lower division with substantive engineering courses and laboratories in order to provide students with maximum flexibility in choosing career paths. Finally, computers play no role in course instruction throughout the lower division curriculum and almost all instruction is in the conventional large-lecture-class mode.

. The challenge is to enhance the curriculum, draw the interest of the students and faculty, but at the same time maintain the full benefits of a comprehensive research university environment.

Reforming undergraduate education is a complex undertaking that certainly requires commitment of resources within an institution. But an equally essential ingredient is multi-institutional collaboration on a broad front in order to provide the necessary moral imperative for change as well as to support wide-ranging innovation and experiment with curricula, educational technology and methodology, that are beyond the capabilities of a single institution. The Gateway Coalition is providing the stimulus and opportunity for

Columbia, in collaboration with other institutions, to embark on a substantive restructuring of its undergraduate curriculum. The aim has been to formulate desired new educational goals and to implement them in ways that are doable, acceptable and attractive to faculty and students and that may serve as paradigms for change for other institutions and for the future.

The two themes are being implemented by a number of specific and concurrent thrusts:

- 1) Creation of physical facility and a unique high-level
- 2) Development of freshman course in conjunction with lab
- 3) Changing the calculus sequence
- 4) Interacting with other components of the University, such as Mathematics, Chemistry, Physics, etc.

SEAS has launched successfully a major new initiative to create an outstanding computer-mediated learning laboratory for first year students that will be the center-piece of a major restructuring of its undergraduate curriculum for the 21st century by leveraging substantial resources raised from government and industry that will bring to fruition this new and exciting enabling tool that will change the way undergraduate engineering education is structured and delivered at Columbia in the future.

Experience and Support from the Existing Gateway Learning Laboratory

The Gateway Learning Laboratory is a physical infrastructure within engineering of a networked electronic studio and classroom employing high-level commercial and in-house software for applications, multimedia authoring and classroom presentation. The Laboratory was created to encourage and provide resources and direction for new and innovative educational efforts in undergraduate education. It became a focal point for enabling curriculum reform. In a unique experiment *all* freshmen were provided with access to advanced workstations and software to introduce them to engineering in a real-world context in order to provide insight into what engineers do and how they work on

real projects. New courses and electronic modules for the freshman/sophomore level have been created and implemented which exploit multimedia techniques to provide an introduction to 3D engineering graphics, modeling and animation and to present some engineering design concepts that traditionally are provided only in upper division course work.. Students explore the Internet/WWW, create their own home pages and send design projects over the Internet to rapid prototyping manufacturing machines. Physical model simulations with highly interactive 3-dimensional graphical user interfaces have opened a new and extremely relevant engineering world to the undergraduate educational experience. The on-going development of new course materials has been a collaborative effort involving students, engineering faculty and faculty from the sciences, mathematics, and architecture. The emphasis in the Laboratory has been on the use of interactive tutorial and learning modules with the instructors serving more as mentors than lecturers.

The School's 8 year-long experience with the Gateway Laboratory as a powerful enabling tool for curricula restructuring and the handling large numbers of students in a learning environment has been invaluable in the development of The efforts in the Gateway Laboratory have produced a cadre of faculty and students with the necessary skills to exploit computer-mediated learning environments. The organizational infrastructure of the Gateway Laboratory with its fulltime manager, a large number of student teaching assistants, and other institutional resources, will be utilized to help operate and maintain the proposed HP facility as an integral part of the overall Gateway enterprise. It thus provides a natural extension of curricula reform and restructuring into the upper and graduate levels.

(It is useful to distinguish the efforts associated with the two phases of funding.)

Major accomplishments supported and/or fostered by Gateway at Columbia in Years 1-5:

- Collaborated with the Mathematics Dept to institute computer-algebra aided calculus courses now in place for two years– see calculus textbook that acknowledges Columbia/Gateway contribution

- Collaborated with the Chemistry and Physics Departments to change the freshman-sophomore sequences in chemistry and physics- see new course sequences in the forthcoming engineering school bulletin for 1997-98.
- Designed and created the Gateway multimedia workstation lab for engineering students-the premier multimedia facility on the campus-draws major financial support from both the University and School administrations -over a dozen courses given in the lab each year, most did not exist prior to Gateway -mostly undergraduate courses
- Collaborated with the Chemistry Department to create Chem/Gate – a CD-ROM based course in freshman chemistry for engineers and non-engineers given in the Gateway Lab with engineering support- partially supported by the Administration-given twice in the past
- Created and instituted a one semester required freshman introductory engineering course utilizing the multimedia capabilities of the Gateway Lab -presented by several faculty and students in team mode- extremely popular with students-given three times in the past
Was successfully employed to justify the award of an independent NSF grant- “Design First: A Freshman Engineering Experience”- joint with the Teachers College for assessment and evaluation of design modules-experimenting with JAVA and other on-line technologies
- Created and instituted six elective freshman/sophomore introductory technical courses in various disciplines- students are required to take at least one and encouraged to take two in order to learn about different disciplines-three have been given once in the past-all are expected to be in place in 1997-98
- Collaborated in creating a CAD lab for mechanical engineering and several related course linked to the Gateway Lab for rapid prototyping , concurrent engineering, and product design-a new course “Introduction to Product Design” in the Gateway Lab will be available to sophomores in 1997-98
- Created and instituted a highly acclaimed *science elective for the liberal arts college* taught by engineering-“Technology and the Rise of Modern Industry”- serves as a non-technical elective for engineering students-given twice in the past

- Instituted a new multimedia approach to “engineering graphics”-a 3D modeling course in the Gateway Lab for sophomores-emphasizes visualization as an engineering tool but is taken by large numbers of non-engineering students-given three times in the past
- Encouraged and supported the efforts of several engineering departments to make major changes in their curricula to reflect the reform in the freshman-sophomore programs, the extensive use of the Gateway Lab and WWW technology-see new curricula in the forthcoming engineering school bulletin for 1997-98.
- Introduced minors in each of the engineering disciplines and in economics to encourage students to explore in modest depth beyond their major and even into non-engineering fields-the economics minor is in place while others are under review and will be in place in 1997-98
- Collaborated with the University Registrar and the Teachers College to develop an automated longitudinal tracking system for assessment and evaluation studies
- The Gateway Lab has been a useful tool in several programs that are associated with attracting K-12 and underrepresented populations – electronic links and student mentors provided to some public schools-first students drawn through this association entering in 1997-98-intellectual links also established with a major minority institution, Morehouse College in Atlanta- the first student coming in 1997-98
- The Gateway Lab has been effective in providing special seminars throughout the year to large numbers of alumni that wish to become current in multimedia and WWW technology- see several articles about Gateway in the alumni newspaper

Plans for Years 6: Institutionalization of Reform

From the beginnings of its participation in the Gateway Coalition, Columbia has adopted the view that exploiting new and emerging educational technology offered a powerful means for creating a new learning environment that would impact the institutional culture and motivate the restructuring of the curriculum. It has indeed turned out to be a uniquely effective catalyst that has induced the faculty to explore cross

discipline collaboration at the instructional level, and to experiment with new curricula and new modes of instruction. The accessibility of an advanced multimedia facility, the Gateway Lab with powerful user-friendly software has generated a high level of interest in pursuing reform by faculty and students campus-wide as indicated by the above accomplishments.

Thus the educational environment in the School (and in the University) has changed significantly from what it was in the pre-Gateway era. By creating a unique, high-end and inviting technology environment the Gateway Lab, and its now multiple links, have encouraged and supported both faculty and students to explore new directions with respect to both the curriculum and its delivery. Each engineering department is vigorously pursuing major curricula reform, some of which has been listed earlier, inspired by Gateway related projects. At least a third of the faculty are using WWW technology in some capacity for instructional purposes.

Groups of faculty from a number of divisions of the University (science, engineering and others) have created this summer a new faculty/student enterprise at Columbia called *Instructional Technology Cluster*. The purpose is to provide a supported campus-wide forum for innovators and early adopters of enhancement of undergraduate curricula through the use of information technologies. Resources are being provided by the Office of the Vice-Provost and the science departments. It is planned that in Year 6, the School of Engineering and Applied Science through its Gateway project, will be a major participant in this information technology enterprise. It has already enrolled a number of engineering faculty. Special engineering oriented workshops in the Gateway Lab that promote the development of web-based courses will also be offered in Year 6.

These accomplishments in curricula implementation and their concomitant employment of information technology are merely part of the broader concept of reform. Meaningful reform must also include mechanisms of assessment and evaluation so that the best and tested practices are incorporated in the curriculum and are subjected to review on an on-going basis. In Years 3-5 assessment was process oriented. The focus

was on the use of various instruments of assessment, the logistics and related problems of introducing them into the classrooms associated with specific Gateway funded projects. The essential idea was to develop experience with introducing faculty and students to the utilization of instruments of assessment in real course-classroom settings. The projects assessed were varied and unrelated except for the focus on the use of new technologies. The instruments of assessment employed were conventional.

In Years 6-10 assessment will be subjected to more scientific control studies which will track over time the impact of new curricular developments on student outcomes. Through joint efforts with the Teachers College in Year 6, a plan to assess and evaluate the new lower division curriculum will be in place for the class of 2001. The longitudinal tracking already in place will be refined and automated during Year 6 as well, in collaboration with the Registrar and the Teachers College.

Student perspectives have played an important role in the school's efforts at reform. Students have been members of the Strategic Planning Committee and serve on the Committee On Instruction where all curricula matters are reviewed. The planning and implementation of the successful freshman Gateway course has been a highly collaborative effort between faculty and students. In several of the courses utilizing the unique Gateway Lab, the students play an important role in partnering with faculty in developing and structuring content and delivery. The school has a broad-based formal undergraduate research program, which is well regarded by students and brings them into direct association with senior faculty. Numerous surveys among students conducted for evaluation purposes and on file with Gateway Central provide some positive evidence that students have been and are playing a role in the change process. In Year 6 it is planned to expand student involvement in curricula reform and its evaluation by utilizing student organizations to organize workshops and related activities that will address student concerns.

The engineering school has an array of programs that attempt to deal with minority and women recruitment and retention. The programs have achieved notable

success with respect to women. The school has an excellent record in attracting women to its programs-they comprise approximately 28% of the freshman class. While it is true that the school has not achieved the level of success that it would like in the area of minority recruitment, it is making strenuous efforts to develop new strategies to ensure diversity in its student body. In fact it has established new partnerships with more than four large K-12 minority public schools in New York City to develop joint programs that will provide access to the resources of the school. In its efforts to attract minority transfer students, the school has entered into a long-term agreement of articulation with Morehouse of Atlanta, a major minority college. Morehouse has appointed the Columbia Gateway representative to serve as an advisor to their programs on attracting minority students to science and engineering. It is planned to develop more intensely these relationships in Year 6 and to increase significantly the diversity in the student population.

The Dean has an Advisory Council comprised of industrial leaders that meet several times a year to review curricula and research programs; a number of programs have separate industrial advisory boards. The Gateway representative from Columbia has on several occasions made major presentations and engaged in dialogue with the Council on curricular reform growing out of Gateway activities. The Dean has asked that they create internal review boards for each department. They have just completed the first such review and a report is being prepared that provides an assessment that will serve as model for such additional reviews in Year 6.

The engineering school has over two dozen adjunct faculty from industry teaching both undergraduate and graduate courses, particularly design courses, on a regular basis. Many supervise undergraduate design projects drawn directly from industrial interests. As the emphasis in engineering curricula shifts to reflect a more direct concern with product design and concurrent engineering we are more frequently engaging industry as a partner in several of our new curricular undertakings. We have begun to coordinate a group of companies that are offering direct participation in some of these ventures. In Year 6 we plan to formalize these activities so that they become a part of the reform process.

In a striking departure from the past, the Dean is considering the appointment of a highly respected and experienced engineer from industry who will serve as full-time Associate Dean For Industrial Relations. As a consequence major programmatic changes involving industrial partners are being planned. It is planned to formalize some such arrangement as part of the efforts in Year 6.

Although several of the initiatives launched by and through the Coalition have begun to impact Columbia, much remains to be done before institutionalization can be said to have occurred. It is now time to systematically test, scale-up, implement and assess/evaluate these many processes and activities on an institutional basis in order to:

- infuse the best of these pedagogical and other new practices into the institutional culture to produce systemic reform, and
- transfer to the institution the obligation to provide the infrastructure, namely the human and fiscal resources, necessary to maintain the resulting systemic reforms.

The objective is to reallocate and redirect the University's resources at several levels of commitment to accomplish reform of undergraduate engineering education in a manner consistent with the Gateway goals enunciated previously and to perhaps help serve as a model for reform at other like institutions.

The first two years of Gateway work at Columbia focused on the creation of an electronic-mediated learning laboratory for the School and the concomitant development of new courses, particularly for freshmen (to be extended to upper level courses in the next stages) in which the computer serves as a universal laboratory tool. A state-of-the-art electronic classroom was completed in the summer of 1994 and represented a major new initiative at Columbia. The on-going development of course materials was a

collaborative effort at Columbia involving engineering departments and faculty from the sciences, mathematics, architecture and others, which stressed the integrative, interdisciplinary nature of modern engineering and technology. The emphasis is on the use of interactive tutorial and learning modules with the instructors serving more as mentors than lecturers. Physical model simulations with highly interactive 3-dimensional graphical user interfaces opened a new and extremely relevant engineering world to the undergraduate educational experience. The modules were designed to be accessible to students with no prior engineering knowledge but involved substantive materials dealing with process engineering, architectural and engineering design, rapid prototyping, construction management, and other topics that are of significance to the educational process but which also will attract and hold the interest of beginning students. Related materials from other coalition schools are being exploited as well.

Recommendations of the Strategic Planning Committee

In 1994, the Strategic Planning Committee of SEAS issued a report that recommended a major restructuring of the undergraduate engineering curriculum which would be responsive to the deep and rapidly evolving changes taking place in the science and practice of engineering. As the Committee stressed, these changes are occurring on a scale and in ways not experienced heretofore, and it is unrealistic to expect programs designed in the pre-computer age to continue to serve engineering education well with little more than some incremental and cosmetic changes. The broad objective is to provide students with the knowledge and tools to create new interdisciplinary technologies and design new products as engineers, which will make them highly competitive in world markets whether or not they practice engineering, and which will prepare them for life-long learning, the task of acquiring new knowledge as necessary.

We were not alone at Columbia in recognizing the imperative for meaningful and carefully crafted changes in the curriculum. President Rupp publicly addressed the University's commitment to make undergraduate education and its reform high priorities for the next decade. The broad goal is to recraft curricula to meet the needs of the

information age but also to provide more exciting, stimulating and flexible learning environments that will attract, retain and provide expanded opportunities for a more diverse student population than in the past.

The mathematical and physical sciences are also engaged in innovative initiatives aimed at modernizing instruction at all levels and have established working partnerships with SEAS. The reliance of the engineering curriculum on a wide range of independent science disciplines and departments and an academic culture dominated by research and graduate education makes this synergy essential. The Scope Committee has been able to leverage SEAS involvement to help induce cross discipline collaboration and support for experiment with new curricula and new modes of instruction. This campus support is critical for initiating reform in the engineering curriculum and in enabling SEAS efforts to impinge on other programs in the University.

In its report, the Strategic Planning Committee set forth a number of broad goals and recommendations to provide a framework for guiding SEAS efforts at reform. These are summarized below.

Goals and Recommendations for Curricula Reform

The curriculum should be restructured to achieve the following goals:

- Immerse engineering students in engineering design, practice and philosophy as early and as pervasively as possible to capture their interest and enthusiasm immediately.
- Clearly differentiate engineering curricula from science and mathematics programs.
- Induce more prospective students to study engineering by providing a more interesting and exciting curriculum of study.
- Introduce and integrate the computer into the curriculum as an intellectual and professional tool at all levels of study.

Among the most interesting innovations being explored at peer institutions to achieve similar goals is an “inversion” of the traditional engineering curriculum. This philosophy

emphasizes “engineering up-front” wherein engineering and some of its functional core are introduced in the first two years and sustained throughout the four years of undergraduate education. The key characteristics of this approach are:

- Introduction of engineering courses, including design concepts, early in the curriculum, i.e. in the First and Sophomore Years.
- Integration of mathematics and basic science instruction in the lower division curriculum with their applications in engineering and engineering science.
- Application of the “just-in-time” philosophy to the curriculum, i.e. teaching theory in time proximity to its use in engineering applications.
- Substantive integration of computer use into the curriculum beginning with the first year program using well-established commercial software such as Mathematica, Maple, Mat Lab, AutoCad, spreadsheets, word processors, etc. and extending throughout the curriculum.
- Early integration of an engineering laboratory component into the curriculum, complemented by substantial computer simulation.
- Introduction of advanced science/mathematics courses into the upper division made possible by shifting some design courses to the lower division.
- Shifting some liberal arts courses to the upper division programs.

Recommendations:

To begin the process of change, the Committee recommended the following specific proposals:

- A year-long interdepartmental course should be developed at the First Year level that, through the use of one or more implementation projects, heightens the interest of students in the practice of engineering. It should introduce and use the computer as an intellectual and professional tool in the process. Students would be organized into small teams to handle different parts of larger projects to encourage the teamwork that is an essential element in the profession. The interdisciplinary nature of engineering should be stressed and used to encourage the notions of concurrent design.

- Mathematics, physics, and computer programming courses should be realigned to provide either contents to the new freshman course or to be appropriately concurrent. It would be desirable to experiment with the “just-in-time” philosophy appropriately modified for pedagogical reasons when necessary, in the teaching of mathematics, physics, computer science, and basic engineering skills required for the above course. [The Departments of Mathematics, Physics, and Chemistry have shown an interest in working with the School to explore new modes of instruction.]
- Departments in the School should be encouraged to begin their own courses in the sophomore year, following the new freshman course. The departmental courses would begin to provide some specialization building on the First Year experience. Combined Plan students can be accommodated since they almost always enter Columbia with substantial mathematics, physics, chemistry, and computing know-how and are anxious to take specialty courses in engineering.
- More encouragement should be given to providing undergraduate project experiences building on the new freshman course and departmental specialties in the sophomore year. Departments should consider tailoring some of their courses in the Sophomore-Junior years in the form of projects or perhaps permit the most promising students to substitute project courses for some required courses. These would provide a better base from which to develop more advanced design courses.