

The Changing Engineering Educational Paradigm

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INTRODUCTION

The total engineering enterprise has an unparalleled role in our nation's long held precepts of the citizenry's "unalienable rights to life, liberty, and the pursuit of happiness". Whether we translate those words into the current terms of security, defense, health care, wealth production, entertainment, or others, the foundation of that enterprise is its engineering educational system. That system provides the world with the creative talents of emerging professionals who will drive the economic engine, the betterment of society and enrich the human condition in the decades ahead.

The post World War II era saw the emergence of the engineering science influence in engineering education. That very positive movement, largely attributed to its MIT origins, consolidated the scientific foundations of engineering. However, after decades of increased emphasis on engineering science, engineering undergraduate education was becoming largely disassociated from the practice of engineering. The emphasis on analysis had outpaced the incorporation of synthesis and design as well as a number of broader educational and intellectual imperatives that were becoming increasingly evident.

Concurrent with the building of the analytic emphasis over the decades, the undergraduate engineering educational experience became increasingly fragmented into what appeared to the student as independent parts. As one author¹ described our educational process generally she noted that "Schools break knowledge and experience into subjects, relentlessly turning wholes into parts, flowers into petals, history into events, without ever restoring continuity". Yet there were, and continue to be, strong pressures to add new technical subject matter as well as pressures and national agendas which called increasingly for a more rounded engineering graduate with the ability to function in the socially interactive, communicative, and business climate of modern industry.

The mid 1980's witnessed a number of reports of studies undertaken by many organizations; beginning with the National Research Council² and followed by reports from the National Science Board³, the American Society for Engineering Education^{4,5}, the Accreditation Board for Engineering and Technology⁶, and other professional societies. While each of these studies of the undergraduate program was conducted independently by a variety of individuals from industry, academe and government, all came to a few central common conclusions. There was a common call for retaining

¹ Marilyn Ferguson, *The Aquarian Conspiracy: Personal and Social Transformation in the 1980s*; St. Martin's Press; Feb. 1980; ISBN: 0312904185

² "Engineering Education and Practice in the United States -- Foundations of Our Techno-Economic Future"; NRC, 1985

³ "Undergraduate Science, Mathematics and Engineering Education"; NSB, 1986

⁴ "Quality of Engineering Education"; ASEE, 1986

⁵ "National Agenda for Engineering Education"; ASEE, 1987

⁶ "Proceedings of the National Congress on Engineering Education"; ABET, 1987

the basic elements of mathematics, natural sciences, engineering sciences, and fundamental concepts of analysis and design. However, there was also a common call for increased emphasis on synthesis and design; maintenance of depth and strength in technical subject matters; a greater emphasis to deeper inquiry and open ended problem solving; stronger emphasis on non-technical education to develop the historical and societal perspectives; development of management and communication skills; interdisciplinary exposure; international exposure; and preparation for continuing professional development and career-long learning. These mounting pressures on an already over-burdened curriculum created a dilemma and exacerbated further against student time for independent thought, leadership development, and the "Joy of Understanding".

Satisfying such a broad set of demands within the traditional program structure seemed extremely difficult. Furthermore, attempts to address all of those demands evolved a very intense experience that was devoid of early engineering involvement and left little opportunity for intellectual enjoyment. The challenge was clear. The solution, however, was far from evident.

A RESPONSE TO THE CHALLENGE

To address this challenge Drexel University's College of Engineering in 1987 established a group of faculty, under the chairmanship of this writer, representative of all the engineering disciplines as well as the supporting sciences to examine the entire framework of the undergraduate engineering education. After overcoming the traditional momentum for incremental adjustments, this group concurred to think in terms of a totally clean slate and adopted the following five part strategy;

- Identify the desired characteristics of our graduates for the 21st century,
- Identify the program emphases necessary to develop these characteristics,
- Assess the present program's effectiveness in these new terms,
- Identify new program components and characteristics such as content, structure, and methodologies to create these new emphases,
- Develop a strategy to implement required changes while retaining existing strengths.

It is interesting to note that this program examination, with intent of reform to address the stated challenges, began prior to announcements of major government or philanthropic funding initiatives for engineering education. The driver was the intellectual need and national call for change.

The committee began its work of defining a set of characteristics which future graduates should possess to become leaders of the profession. For the sake of brevity they are presented below without rationale or comment. None the less, they formed the basis of the development of the entire program.

- A strong foundation in basic sciences, mathematics and engineering fundamentals
- A capacity to apply these fundamentals to a variety of problems
- Knowledge and experience in experimental methods
- Knowledge and skills in the fundamentals of engineering practice
- Advanced knowledge of selected professional-level technologies
- Strong oral and written communication skills
- A sense of corporate and business basics
- A sense of social, ethical, political and human responsibility
- A historical and societal perspective of the impact of technology

- A unifying and interdisciplinary broad view
- A culture for life-long learning
- A creative and intellectual spirit, a capacity for critical judgment, and enthusiasm for learning.

The Committee then proceeded to define the optimum blend of program emphases to create a total educational experience conducive for the development of the characteristics mentioned above.

Except for its organization structured to accommodate a significant component of cooperative education, Drexel's engineering education program had followed the typical model of sequential layered courses in mathematics and science followed by engineering science and which in turn was followed by professional level department defined upper division courses and a senior design component. The Committee felt that the greatest new impact could initially be made at the lower division (freshman/sophomore) level where heretofore there was little College of Engineering influence or participation. Furthermore, the view was that significant change at the lower division would ultimately be a driver for upper division reform; and so it has materialized.

The Challenge to the Committee at this point was to determine how to establish a structure that would encompass its outlined set of objectives and emphases for the freshman/sophomore years. In an approach traditional and comfortable to the faculty, the Committee evolved a long list of courses that, viewed as a collective whole, would accomplish these goals. Recognizing that time constraints simply would not permit such a set of independent courses the group was ready to accept suggestions for a radical departure from the traditional layered and sequential structure that had been the norm for decades.

With judicious guidance, the Committee determined a structure, philosophy, and subject matter specificity as:

- An interwoven set of programs that are coupled and synchronized so that they complement and amplify one another.
- Vertical integration of the curriculum such that multiple objectives could be achieved within the same course and time period. The lower division student would no longer face a group of isolated individual courses in mathematics, the sciences, computer, introductory engineering and liberal studies but rather a vertically integrated package that would be team developed and taught.
- Engineering up-front meaning that it not simply be the traditional introduction to engineering or survey course but, rather, that engineering be the intellectual centerpiece of the curriculum from its outset.
- Integration of the basic mathematics and sciences unto themselves but then, most importantly, into and concurrent with this new concept of engineering as the intellectual centerpiece. The theoretical base is thus developed around the engineering intellectual issue.
- Integration as a joint initiative between engineering, science, mathematics, and humanities colleagues teamed in planning and teaching these topics with interwoven connections and engineering context. Thus transcending and making more permeable the traditional cross-department and cross-college boundaries within the institution.

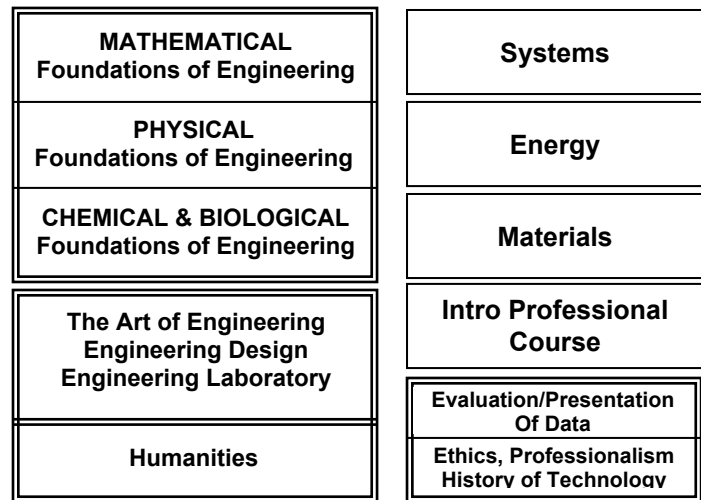
- Increased emphasis on experiential learning through an engineering laboratory in which the exercises teach engineering principles while concurrently providing verification of the scientific theories raised in the classroom and upon which the engineering is based. The theoretical base is identified with and interwoven with the professional discipline to which it is being applied.
- Teamwork as well as independent work structured to develop leadership, organizational management, and oral and written communication skills.

During the period of the Committee's efforts, The National Science Foundation and philanthropic organizations had also been evolving their programs in support of systemic change initiatives of the engineering educational enterprise. The model thus established by the Committee became the basis for a successful proposal of support from the National Science Foundation⁷, the General Electric Foundation, and several corporate sponsors. With that support the program gained momentum and proceeded at a rapid pace.

The first year was devoted to capacity building aimed at both the required educational culture change and program development. Forty-five faculty from across the engineering, science, and humanities departments voluntarily participated in a three-day workshop to explain to one another what the curriculum had been like to that time and then participate in the dialogue towards total restructuring. That faculty-to-faculty learning process, explaining what each of the independent disciplines and components were providing to the engineering curriculum, was an enlightening experience for many. Even the seasoned faculty member had not previously had such a holistic view. To some extent this insight served as a further driver for reform. Faculty teams evolved and the initial experimental curriculum developed.

The subject matter was initially organized into four interwoven sequences replacing and/or integrating material from thirty-seven existing courses in the university's traditional lower division curriculum. The sequences, as shown in the figure to the right for the freshman and sophomore years respectively are entitled the "Mathematical and Scientific Foundations of Engineering" (Mechanics and Calculus, Electromagnetic Theory and Applications, The Structure, Properties and Interactions of Matter and Living Systems), "The Art of Engineering" (Engineering Design, Engineering Laboratory, communications skills, and humanities linked); "Energy; Systems and Material" in the sophomore year, the "Personal and Professional Enrichment Program" (Humanities, Data Presentation and Analysis, Ethical Considerations). Embedded in this interconnected set are the emphases on early involvement in engineering with the mathematical and scientific underpinnings brought in context; engineering design as the critical essence of the profession; the unifying and interdisciplinary fundamentals of general practice; the synergistic relationships between science,

Engineering Core Curriculum



⁷ The E⁴ project was supported, in part, by the National Science Foundation award USE-8854555

engineering, and at times the humanities; the central importance of experimentation; and the imperative for superior communication skills and life-long learning in professional practice. The student, as an emerging professional, is placed at the focus of activities in which students and faculty work as a team. Later, "Introduction to University Life" was embedded into the freshman sequence and, at the behest of the engineering departments, time for a departmental specific course was allocated in the last part of the sophomore year as well.

An examination of various outcome measures included measurements of laboratory skills, evaluation of performance in freshman design projects, critiques of written and oral presentations, student retention rates and progress to degree completion. Early investigations compared the cumulative grade point average of those students participating in the pilot integrated curriculum with those students still taking the traditional curriculum. There were significant differences throughout the initial pilot period and into the transition period. An interesting and unexpected finding also noted was that during the transition period the performance in the traditional curriculum sections also increased, although to a lesser degree. The reason for this influence was felt to be the impact that the pilot program was having on some of the traditional course offerings as new materials and pedagogies were disseminated.

While differing slightly each year the retention through the end of the sophomore year for the first two cohorts averaged 21% greater for the experimental group than the control (traditional program) group. "On track", identified as completing all work expected for an on-time graduation, averaged 94% greater for the first two experimental groups as compared to the control. Furthermore, the students in the experimental groups clearly expressed the characteristics of problem solving, negotiation skills and critical integration skills as critical for engineering practice while students in the traditional program related engineering primarily to be the application of math and science. They had not yet had the opportunity for engineering up-front or for learning in context. The first graduating class that completed the experimental program showed remarkable differences in their success rates. Of those in the traditional program the on-time engineering graduation rate was in the mid-40% range while those who had participated in the experiment had a graduation rate in the upper-60% range; about a 50% improvement. Even for those who had started in the experimental engineering program but then decided to change their interests to other areas within the University an increase in on-time graduate rate was noted. These results drew considerable attention within the University.

The early success of the program, and the acceptance of the paradigm shift, led to several important milestones in 1992. At Drexel University a two-year phase-in process was begun to ultimately adopt the experimental program as the institution's program for all engineering students. Furthermore, the interest in the E⁴ approach brought together many interested groups and in 1992 a Coalition of institutions was formed to go beyond the E⁴ program.

EXPANSION AND EXTENSION

With sponsorship from the National Science Foundation the Gateway Engineering Education Coalition, headquartered at Drexel, was charged with taking this experiment to broader dimensions under the leadership of this writer. The Coalition was to be a collaborative of academic institutions selected for their diverse institutional structures and cultures. This partnership would embrace the challenge of altering traditional engineering education from a singular focus on course content to one inclusive of the development of human resources, the broader experience founded on a

multidisciplinary integrated education, bridging of educational research and development across institutional and collegiate boundaries, and changing the educational culture. Operationally, while the E⁴ experiment (later renamed tDEC as it was institutionalized at Drexel) permeated traditional boundaries within a single institution the Gateway Coalition fostered similar intra-institutional changes as well as transcended the traditional inter boundaries across institutions vis á vis undergraduate education.

The Coalition's functional goals were to:

- Extend the Drexel E⁴ experience of the freshman/sophomore years to the broader set of institutions;
- Extend the earlier concepts to the full engineering baccalaureate program;
- Address issues beyond program restructuring and curriculum reform to include professional development of students and faculty. For students this includes such aspects as teaming across institutional boundaries, addressing ethics in the context of an engineering issue, oral and written communication skills, and professionalism. For faculty the new concept of professional development would go beyond disciplinary content and disciplinary research to include the understanding of different student learning styles and experimenting with different educational methodologies;
- Encourage programs that increase the percentage of under-represented minorities who graduate from our engineering programs by bringing these issues to the forefront of discussion among the faculty and all stakeholders as well as encouraging innovative initiatives;
- Employ leading technologies in the classroom when it can make the educational process more effective, as well as using leading technologies to permit students to conduct experimental activities from distant locations and across institutions;
- Develop an extensive assessment and accountability process defining measurable outcomes and track them while using them for feedback to improve the system; and
- Further extend the experimental work of the Gateway Coalition to additional institutions by linking the Coalition schools collectively and individually with other schools of engineering.

While the Drexel experiment (ultimately an institutionalized and sustained program) required faculty and institutional intellectual buy-in from within a single institution the Coalition required a common vision, new organizational processes, and sustained collective working level involvement from faculty and administrators to meet the above referenced common goals. To achieve this the Coalition was structured to have a Council of Deans, a Governing Board and an External Advisory Board. The Council of Deans addressed the policy issues that link the Coalition's agenda to that of their individual Colleges. The Governing Board member was the personal representative of the Dean and, with assistance of the central organization and operations, he/she served as the intra and inter-institutional connection. The Governing Board collectively established the direction and agenda while the individual Governing Board Member served as his/her institutional programmatic activities leader to accomplish the details of implementation.

The first phase⁸ of the Coalition served to innovate and develop the initial products and processes to bring those ideas to both local fruition and disseminate the results of that work. During this period extensive cross institutional initiatives were begun. It was the policy of the Gateway Coalition to support primarily those initiatives that transcended institutional boundaries. This approach was selected to minimize the potential for self-centered institutionally parochial efforts. It was the policy of the Gateway Coalition to support institutional efforts toward the common agenda in proportion to the degree by which they participated in program initiatives rather than by a formulaic division of funds. The second phase of the Coalition was to establish the processes to implement the earlier innovations, institutionalize these, and develop the culture change to permit them to become sustainable. The dissemination of the results of this work has been pervasive through both phases although much more intense with a specific agenda during the second phase. The Coalition's Focus Areas include curriculum development and implementation, professional development, outreach, instructional technologies and methodologies, assessment, and linking and sharing beyond the bounds of the core set of institutions.

The first set of challenges identified above relate to curricular extensions which coincidentally would be an area in which faculty felt comfortable. The organizational and pedagogical approach would be different, yet it never the less was a place for faculty to naturally gravitate and begin participation in the broader agenda.

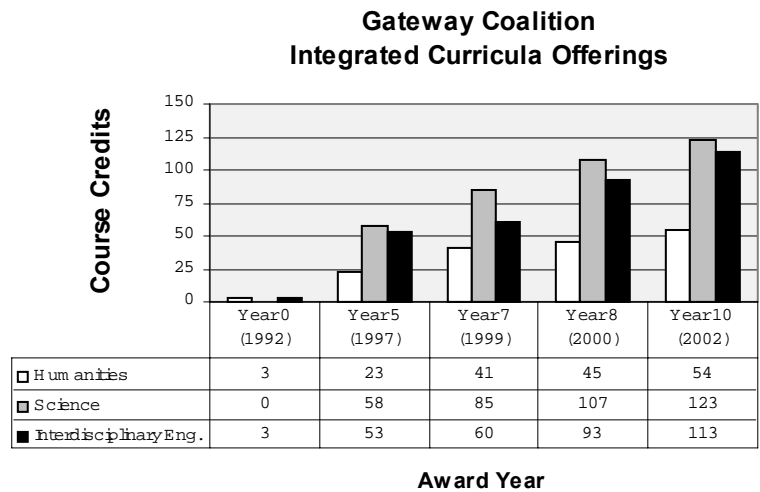
OUTCOMES AND CULTURE CHANGE

With an emphasis on engineering design as both a driver and motivator, Coalition schools have implemented curricular changes bringing comprehensive design experiences into the freshman year enabling first year students to grasp the foundation mathematics and sciences in an engineering context. This was a direct extension from the Drexel experience and served as a catalyst for further curricular and cultural changes throughout each institution. Almost all freshmen at the Coalition schools participate in a significant freshman design experience. Design as a driver and motivator extends further and the curricular innovations of the Coalition spanning the full matriculation period of freshmen to seniors; many with a multidisciplinary emphasis. One piece of evidence of this culture change is the evolving, interdisciplinary nature of the curricular offerings now pervasive in the Coalition Schools.

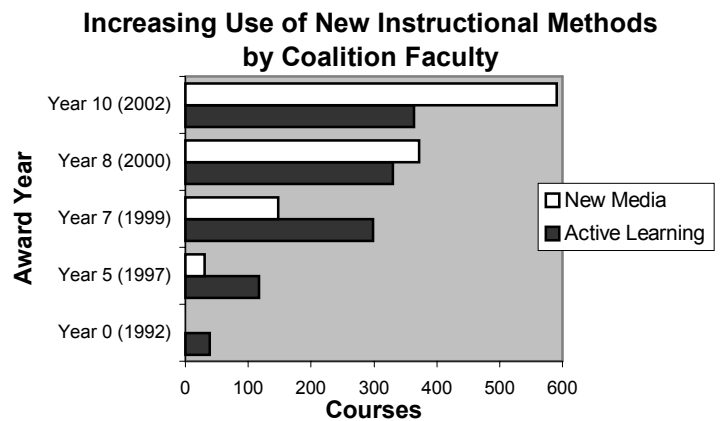
Early in the Coalition's history the Coalition Governing Board decided to focus on a limited set of specific curricular content areas as a means to demonstrate what can be achieved. Resource limits and the potential of becoming spread too thin precluded any plan to cover a complete curricular spectrum. The key strategy was to provide illustrative models in important curricular areas. Examples of course developments and modules beyond the freshman experiences include such areas as systems and control, materials engineering, environmental engineering, engineering biotechnology, concurrent engineering and manufacturing, as well as embedding the issues of ethics

⁸ The Gateway Engineering Education Coalition, headquartered at Drexel University, was organized in two phases. The partner institutions of the first phase (1992-1997) were Columbia University, Case Western Reserve University, Cooper Union, Drexel University, Florida International University, New Jersey Institute of Technology, Ohio State University, Polytechnic University, University of Pennsylvania and University of South Carolina. The second phase (1997-2003) partner institutions are Columbia University, Cooper Union, Drexel University, New Jersey Institute of Technology, Ohio State University, Polytechnic University, and University of South Carolina. The Coalition has been supported in part by the National Science Foundation awards EEC-9109794 and EEC-9727413.

and communications within the engineering program. These were developed as multi-institutional cooperative initiatives. In addition, modules on such emerging fields as wireless communications, medical robotics, waste containment, nanotechnology, network security, internet technologies, and network security were added to the portfolio of available resources as a vehicle to address emerging technologies. While such massive curricular development is considered a major Coalition achievement, the unique aspect of this work is that these innovations take advantage of the latest instructional technologies and pedagogical approaches. Curricular materials are replete with cross-disciplinary content and created to use digital instructional technologies and active cooperative learning techniques in the service of the learning process. As the figure below illustrates, there has been a continuously increasing number of courses that formally integrate the basic sciences and humanities with engineering; serving to enhance the engineering course while providing a contextual setting for the supporting discipline materials. Increasing interdisciplinary course activity across engineering disciplines is noted as well. As will be subsequently described, the Coalition considers the best means to disseminate these and other products of its work is through a web repository that will permit search, preview, and downloading of complete programs, or samples of others where the complete materials are available through traditional publishers.



Changes in the Gateway engineering educational process have led faculty and students to participate in professional development with a broader set of educational competencies leading to a changed educational culture. For faculty these changes involve the use of new educational support tools, an increase in understanding how students learn, and how faculty can help students increase their ability to apply new information, new tools, new skills, and new approaches. Through such mechanisms as intensive, hands-on workshops, seminars, and technology-mediated faculty exchanges, advanced teaching and learning concepts have permeated throughout the Coalition's faculty. Major increases in the use of cooperative learning activities and new media digital instructional technologies have occurred as demonstrated in the figure to the right. Increasingly, instructors are incorporating a more active, cooperative learning approach to support both the reception and processing of new information by the student learner. Among the Coalition schools faculty attending educational conferences has more than tripled and courses in which faculty use cooperative learning methodologies has increased nine fold. The impact is evident in



the more than three fold increase in the number of senior faculty engaged in lower division courses and the twenty fold increase in the number of upper division courses taught by interdisciplinary faculty teams.

For students there are new programs that integrate communications skills, teaming and interpersonal skills, and the ethical dilemmas faced by engineers. In keeping with Gateway's fundamental premise, these skill-based activities are imbedded within the student's educational program to bring the issues to life in real context rather than as separate programs to be provided outside of the College of Engineering. Within the Coalition schools the number of students participating in engineering courses that formally integrate communication skills has increased ten fold and the number in courses that formally integrate ethics has increased fifteen fold.

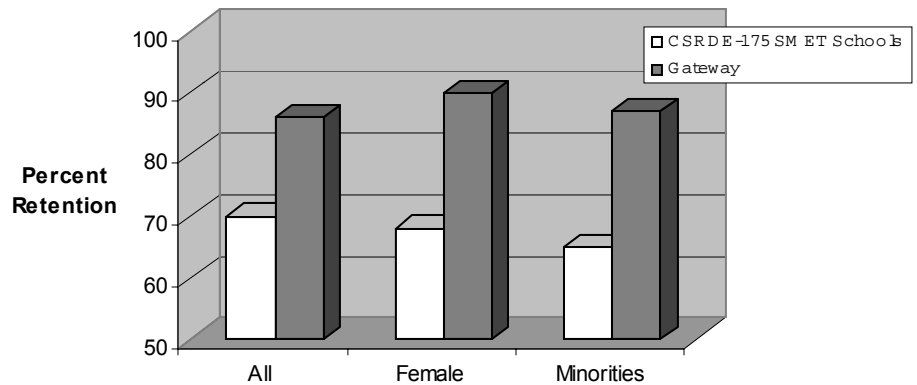
Outreach takes on several forms for the Coalition; programs that foster retention and timely graduation of underrepresented populations within the institution and linkages to pre-college students and community colleges to enhance the interests and opportunities for students to select engineering as a profession. Within the institutional programs an early Governing Board decision was that Gateway support for programs targeted to either attract or retain greater numbers of underrepresented students would be for new innovative initiatives and not to supplant the support already provided through other means at most institutions. While specific targeted initiatives have been supported, the objective was to also ensure that the issues facing the underrepresented groups be included and integrated into the plans for each project as it is initiated thus forming a foundation that is inclusive and beneficial to these groups. This concept is in keeping with the view that the Gateway programs themselves, as they are institutionalized, should be able to provide improvement in the many factors that lead to better attraction and retention of underrepresented groups in engineering education as well as serve the institution's general engineering student population.

Two train-the-trainer types of innovative target programs have been a Women's Leadership Series and a program called Getting Plugged-In. The former served in development of leadership and career fulfillment objectives for women staff, faculty, and students. The latter, targeted for minority students, is designed to facilitate quality faculty/student relationships and to how to introduce students to the practice of building networks as well as identify and pursue pre-professional engineering opportunities. The on campus facilitator organizes a seminar with a full day of exercises which teaches students how to initiate interactions with their professors and increase their awareness of research opportunities. Another targeted program to address African American student engineering career issues was the establishment of formal linkages between Gateway institutions and HBCU institutions. Formal documents defining the linkages between the institutions were signed by the senior leadership of both partners. Yet another exciting program is the Educational Learning Assistants (ELA) program oriented to increase the retention rate of resident minority students. Now institutionalized at one Gateway school, the Educational Learning Assistants reside in residence halls and develop and maintain regular contact with minority students. The ELA provides students with tutoring, peer counseling, and academic support workshops on career development and interpersonal skills as well as timely feedback to the professional staff who are then able to implement effective intervention regardless of whether the problems are academic, financial, or social-emotional. The results of this program are quite impressive demonstrating an increase in continuing freshman rates and increased GPA performance.

Many of Gateway's educational innovations, such as engineering up-front, student professional development and mentoring have resulted in increased retention rates from 1st to 2nd year and 2nd to

3rd year as well as increased graduation rates across all partner institutions. Reviewing one recent Gateway cohort and benchmarking the results with the latest available data from a national retention study (1999), clearly demonstrates that the Gateway schools exceeded first to second year retention rates significantly when compared to national programs specifically focused on science, math, engineering, and technology (SMET) (N=175 schools). The Gateway schools, in aggregate for all students, have an 86% retention rate as contrast to the national sample of all students of 70%. The differences are even more dramatic when comparing for those generally

***Gateway Coalition's Curricular, Teaching, and Mentoring Innovations Improve First to Second Year Retention Significantly as Compared to a National Sample**



* This graph compares Gateway's 1st to 2nd year retention rates against a national sample of 1999 science, math, engineering, and technology majors as collected by the Consortium for Student Retention Data Exchange (CSRDE) at www.occe.ou.edu/csrde.

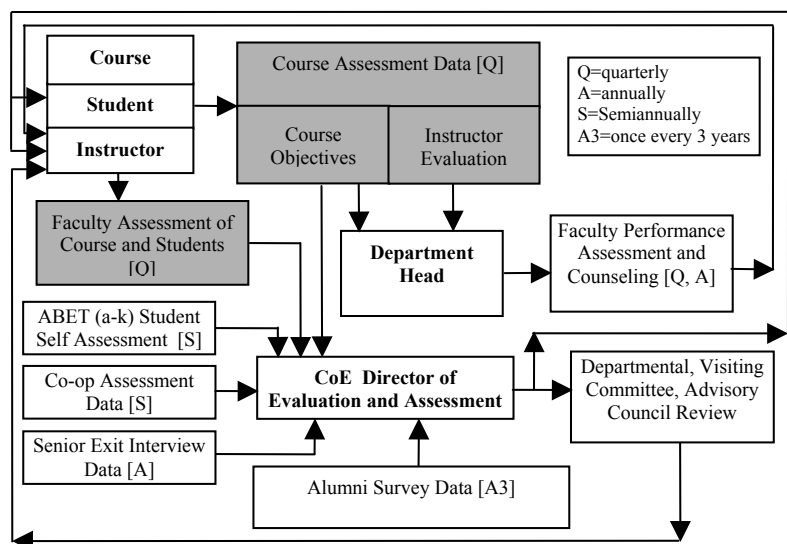
underrepresented in SMET educational programs. The Gateway schools, in aggregate, have an 87% retention rate for African American and Hispanic students versus 65% for the SMET schools within the national retention study. For women, the first year retention data for Gateway Schools is 90% versus 68% for SMET schools in the national study. In general, since inception of the Coalition, the collective retention rates from first to second year for underrepresented minorities has increased 30% and for women in engineering has increased by 20%. Retention rates from second to third year have increased 18% and 20% respectively and the percentage of the graduating class awarded BS degrees in Engineering has increased by 113% for underrepresented minorities and 54% for women.

Outreach is also taking place between Gateway partner institutions and Community Colleges and high schools local to their area. In this model the Gateway curricular developments are being adjusted and shared with these stakeholders in the educational system thus fostering entry into engineering as a profession. Urban schools have been hampered by continued shortages of qualified teachers of mathematics and the sciences. Furthermore, these K-12 students generally do not have the opportunity to learn about these subjects in an applied context. Thus the Gateway Coalition's educational philosophy, if appropriately introduced at the elementary and high school levels, can be very supportive. The Gateway partner institutions undertake many different forms of support programs such as sponsorship of contests, competitions, summer programs and even sponsoring a science and engineering focused high school. Through the Coalition additional K-12 initiatives have been fostered. Some include such aspects as engineering undergraduate students serving as teaching assistants in the K-12 classroom, serving as student mentors; faculty as well as students introducing middle school students to science and engineering experimentation and measurement; and bringing a version of the Gateway freshman engineering program to High School students. These initiatives have had positive impacts on both the K-12 students as well as the involved engineering undergraduates.

Gateway has been innovative and aggressive in anticipating the potential for, and bringing, technologies to new modes of interaction and communication and its impact on the educational landscape. From the very beginning of the program, the Coalition leadership created a Gateway communication infrastructure that enabled and encouraged the Coalition schools to share, on-line, a variety of distributed resources such as faculty, laboratories and learning/teaching tools. The focus has been on expanding the boundaries of instruction beyond the classroom and beyond each institution. This includes electronic sharing of courseware, remote access and control to laboratory and other unique facilities, remote control of student experiments, and video conferencing among institutions connecting students and colleagues. These efforts have resulted in significant gains in incorporating new media technologies into the classroom as well as linking partner schools to external institutions and experts. As noted in an earlier figure above, the collective faculty are now using new media technologies in over 590 courses throughout the seven schools. Use of modern communication technologies have facilitated Gateway's early multi-institution model making network in support of design courses, the concurrent engineering program whereby students from multiple institutions collaborate in design and production, remote control of laboratory experiments, and bringing "the expert" into the classroom. Several factors contribute to this increased usage in new media technologies. A large percentage of Gateway's professional faculty development activities have focused on the integration and application of digital technologies in the classroom. Another factor that has enhanced the use of instructional technologies is that each of the Coalition schools has learned how to capitalize on their strengths in the technology area by forging new interdisciplinary relationships within their institution. A third practice supporting faculty use of technology is the emerging trend to capitalize on student technical expertise with web and multimedia applications. Several Coalition schools have recognized the breadth and depth of this resource and are exploring ways to formalize this unique faculty-student relationship. Finally, the technology itself has evolved since the Coalition's inception but it has, never the less, been the creative vision for use of the technology that brings it into the educational environment.

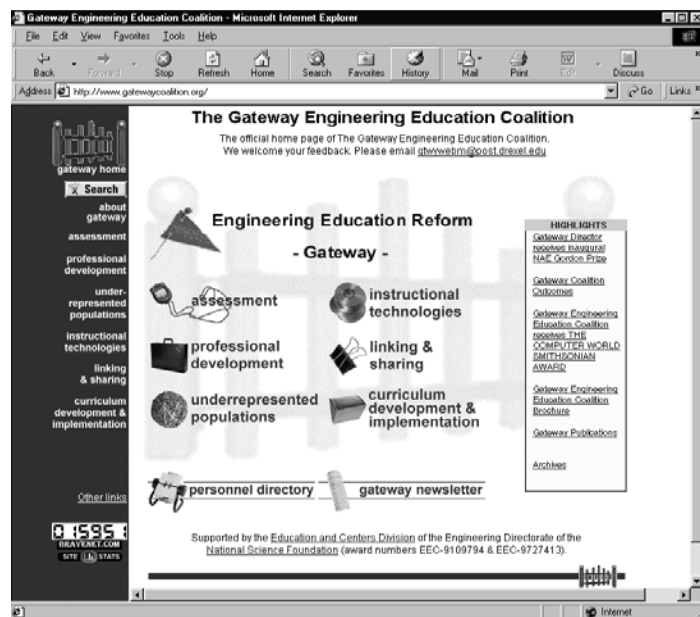
One of the Coalition's objectives has been to embed and institutionalize outcome-based assessment and continuous improvement processes within engineering educational programs, departments, and colleges. This is in keeping with a generally increased focus of attention on outcomes assessment of higher education by industry, government, and academic accreditation entities. The Gateway Coalition has tracked more than forty parameters from year to year from each of its member institutions. The result of that assessment tracking process permits the Coalition to express the status and quantitative results of its efforts.

Taking this process a step further, and borrowing from industry, the concept of continuous improvement has also become a part of the vocabulary. The most relevant example of this is the use of program objectives, student learning outcomes, and feedback loops in the Engineering Criteria of the Accreditation Board of Engineering and Technology (ABET). To accomplish this goal, the Coalition leadership in partnership with the



faculty, have developed a comprehensive, structured approach to identifying and measuring both global and specific engineering learning objectives from the classroom to the institutional level. Through a highly collaborative process, a number of tools and processes have been developed to support the measurement of these objectives. As part of the development process, each partner institution has developed, within their institution, a formal assessment and feedback process. One such diagrammed process is illustrated on the preceding page. It outlines how data from various constituents flows through an academic organization and how improvement decisions are made based on results. Tools and other aids to assist in identifying objectives, establishing outcomes, and creating survey instruments as well as a complete turnkey web-based student assessment program are available via the Coalition's web site.

The Coalition has developed many new materials relating to the curriculum, explored new teaching methodologies, used the newest technologies for undergraduate education, instituted professional development activities, and institutionalized assessment and continuous improvement in all the partner schools. These developments are the elements around which systemic change at individual institutions can be planned and implemented. The results of these developments offer a wealth of examples and pilot programs that can be used for adaptation or full-scale adoption. Essential to this goal is diffusion of the innovations to the broader community. With this objective in mind, the Gateway Coalition has pursued an aggressive dissemination program that includes participation in or organizing numerous professional workshops, published on the order of 500 educationally oriented papers, monographs, conference presentations, published texts, and published electronic media and



distribution of complete products via the Web. Additionally Coalition partner schools have established communications or collaborative associations with over 90 institutions at the four-year college, community college, and some pre-college levels to share information, experiences and results.

Conferences, workshops, and partnerships provide interpersonal channels for dissemination which generally reach a targeted audience with focus and interaction ability. Mass media channels such as publications, electronic media, and digital repositories on the other hand reach a broader community but when used in a

broad information diffusion mode generally lacks interaction. The leadership of the Coalition has decided that long term continuing distribution and dissemination of its outcomes would best be served through use of the Web as a digital repository providing a legacy of its work and wide availability. To address the issues of interaction and support the site will include the "how-to" where innovators have made it available while some products include video and voice support. The primary innovator of a given product will be identified along with contact information. The development of this repository has in itself been a learning experience. For example, in the course of developing many Gateway learning resources, the Coalition leadership and faculty have learned that the process of acquiring content for the web repository does not end once the material is received from the contributing faculty member. Rather, in many cases that work must be

transformed for the intended wider audience beyond those who have had intimate development contact and direct application. This Web repository houses all of the products and processes that have been developed over the ten years of Coalition activity and may at a future time become a content kernel of an intellectually broad digital library.

A LOOK TO THE FUTURE

What does the future portend? Hypothesizing about the future is always interesting yet risky. Some elements of opportunity and challenge are becoming increasingly evident however. Changes in the educational environment for the College of Engineering will take place in at least two aspects. One will be in the education of our engineering students and the other will be in the College's broader role within the University. We are on our way to address the former but the latter has yet to materialize in a significant way.

The educational program of our engineering students in the years ahead will most likely see even more global and cross-institutional linkages. We will see further integration of the important components that round-out and complete the holistic experience of our educational programs making them ever more exciting and rewarding. At the same time the programs will become more technically intensive while intellectually broadening. To achieve this will require new approaches and taking advantage of new tools. Tools, coincidentally, that we engineers will develop for the broader purposes of enriching the human condition. Through such access and program integration our emerging professionals will understand better how to function in a world of far flung facilities with teams of colleagues across many geographic boundaries. Equally important is the intellectual maturity and broader cultural understandings that will come from such integration and linkages. Much of this will be technology enabled. Consider the possibility with visual, touch, force, and maybe even olfactory sensory feedback from a remotely controlled engineering operation or product development. To broaden the horizons and make the integration process the norm rather than the exception think for a moment of a series of web repositories serving as content seeds for a fabulous digital library environment. We might envision a student working with computer based educational modules developing solutions, through sophisticated artificial intelligence interaction, to an open ended engineering problem. As he/she works through several scenarios the names of important historical figures, places or events associated with the concepts, theories, and applications appear as sidebars. The student can digress for a moment and learn a bit about those individuals, places and periods. Furthermore, associated with each is a chain of historical, social, or industrial events that preceded, coincided with, or followed this leader's work; each with text, sound, and video to make the setting most vivid. The tags associated with individual web repositories, be they technical, interdisciplinary, business, or social sciences oriented will be an enabler as the digital libraries transition to technology-mediated resource centers supporting learning communities. Demand will force resolution of the intellectual property issues. Imagine the wealth of knowledge and worldliness, as well as technical prowess, that this student will gain through such self-driven integration. The evolution will continue as the vision and imagination of our emerging engineering professionals are further stimulated.

Just as we have made structural changes, more will be needed and established. The way will be found to make the engineering educational programs more flexible without loss of needed technical strength. Engineering programs will increasingly provide the opportunity and encouragement for students to pursue other intellectually broadening combinations with such areas as business, economics, marketing, entrepreneurship, education, and psychology and other social sciences as well

as combinations with mathematics and the physical sciences. The enabling structures will be many. The former set of combinations may suit those entering engineering practice while the latter perhaps for those pursuing careers at the cutting edge of research. In total, however, the educational system will provide for a new renaissance engineer recognizing multiple career and personal intellectual interests. Technology, and most probably information technology, will play an important role in enabling the extensive functional and time efficiencies that will be required.

Technology will continue to be the driver of the economic engine. This will create increasing need for those in the non-technical disciplines to gain a knowledge base in technology concepts appropriate to their disciplinary level. Thus beyond enabling the intellectual breadth for the engineering program, a demand for the reciprocal will increase and a relatively new role and opportunity for the College of Engineering will emerge. The form of such linkages will also be varied ranging from dual majors to single "service" courses. It will require the College of Engineering and its faculty to function in different educational settings of technical depth. The student audience will be very different in preparation and expectation. The ratio of learning outcomes to time on subject will be expected to be great. While a significant new challenge it will offer an unparalleled opportunity for the College of Engineering to cement linkages with other segments of the University and come closer to the centerpiece of the University.

SUMMARY

The educational enterprise, and faculty in particular, have been very creative in addressing the challenge for change much as we would address any research endeavor. The problem statement was defined, the conceptual framework for solution outlined, and experimental and test procedures initiated. As is often the case, research progress itself raised additional issues to address and the path of inquiry was modified accordingly. The result has been the evolution of an educational enterprise in which engineering has been brought up-front integrated with the sciences, mathematics, humanities and social sciences into a holistic experience which permits our students to learn in context. An opportunity has been afforded to link the societal and historical perspective while embedding the development of communication, interpersonal, organizational, and team building skills. Issues of ethics and societal impact are built into the integrated whole. New paths have been opened in the upper division for greater depth, more interdisciplinary exposure, and cross institutional student/faculty collaborations. Design, the essence of the creative process, has become a motivator and driver from the freshman year forward thus pushing the higher order vision and creative thinking of our emerging engineering professionals. We are merging synthesis with analysis as well as the abstract with societal centered practice. Beyond disciplinary content, however, faculty are also examining educational methods and how we teach as well as what we teach. They are increasingly using technologies to make the educational process more effective and rewarding. Finally, engineering faculty have defined succinct measurable objectives and outcomes at the course and program levels with response data collected, rapidly analyzed and fed back for improvement.

The environment is one of vibrancy and innovation in which the professional discipline of engineering has become the centerpiece of the undergraduate intellectual debate and for which the College of Engineering takes a leadership responsibility. Indeed, a significant and sustainable culture change and paradigm shift is taking place in engineering education. The future looks bright with achievable challenges that will bring further innovations and flexibility to the undergraduate engineering enterprise while also forging strong ties and educational imperatives with other parts of the University.