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Innovations that Changed the Engineering Educational Environment*

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A dramatically restructured undergraduate engineering education programme has been in progress for more than a decade with significant positive results. The programme involves a vertical integration of the basic mathematics, physical sciences and humanities into an interwoven set, together with engineering as the intellectual centrepiece, from the first day that students begin their baccalaureate education. Students learn the early mathematical and scientific foundations in an engineering context coupled with extensive early hands-on experiential learning and engineering design, increased use of technology and an extensive assessment programme. Emphasis has also been placed on increased graduation rates of students from underrepresented populations. The programme bridges traditional barriers across departments, colleges within the institution and across institutions. A coalition of institutions organised to conduct this programme has achieved significant success with many measures including student retention, progress to degree completion, faculty development and educational pedagogy, as well as sustainable educational culture change. The article describes the process of change, institutional implementation, its positive outcomes and a look to the future.

INTRODUCTION

The productive result of the creative talents of engineers drives a nation's economic engine, the betterment of society and enriches the human condition. The importance of an adequate and well-educated technological workforce for research, design and development is central to the world's needs in the decades ahead. It is also important that the citizenry pursuing non-engineering professional paths be somewhat versed in the issues of technology, since they will encounter it in their daily decision making; some of which can have direct impact on the engineering profession.

The educational system plays an obvious and compelling role in providing this critical talent or educational base. While the encouragement of young talent to enter the profession is important, the most direct role for the higher education community is the retention to graduation of those entering the system. Furthermore, it is essential that these talents be developed in ways that lead to more than technical expertise.

The engineers of today, and in the decades ahead, must be able to function in a team environment, often international, and be able to relate their technical expertise to societal needs and impacts. It is that relationship that permits engineers to be the most productive in bringing their creative talents to the development of marketable products and the solution of societal needs. Furthermore, it is also important that colleges of engineering serve a role in technological awareness on the part of a broader segment of the citizenry. Segments of that citizenry will be making decisions that are technology oriented and, depending on their position, may have an impact on the engineering community, as well as on themselves personally.

THE EDUCATIONAL PROGRAMME

In 1988, Drexel University, Philadelphia, USA, began an experiment that changed the structure and organisation of the lower division of the engineering curriculum and which ultimately led to a significant

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revolution in the engineering educational enterprise as the result of adaptation of components of this work by many other institutions [1][2]. This programme brings engineering up-front as the centrepiece of those intellectual issues that confront students and thus brings the study of the basic sciences, mathematics and engineering fundamentals in context and concurrent with open-ended engineering inquiry and engineering experimental methods.

While achieving these objectives, imbedded in the programme, through a group of interwoven course components, students also develop better oral and written communication skills, leadership skills and a host of other important attributes important for an engineering graduate to function well in the socially interactive, communicative and business climate of modern industry. This is coupled with a creative and intellectual spirit, a capacity for critical judgement, an enthusiasm for learning and the opportunity to see enjoyment in the pursuit of engineering studies and an engineering career. Faculty teams break down traditional institutional cross-department and cross-college barriers to plan and implement the restructured programme.

The subject matter at Drexel was initially organised into four interwoven sequences replacing and/or integrating material from 37 existing courses in the University's traditional lower division curriculum. Retention rates of the experimental group increased considerably over the control (traditional programme). *On-Track*, identified as completing the work expected for an *on-time* graduation, also increased.

The success of retaining students in engineering and their progress during the early years of the experiment drew considerable attention. In 1992, it led to the phase-in and institutionalisation of the new programme as a programme for all entering engineering students at Drexel. It also led to the formation of a coalition of institutions to pursue these and even broader goals.

The Gateway Engineering Education Coalition, centred at Drexel University, first extended the earlier integration work to other institutions [3][4]. The Coalition first 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 curricular initiatives were begun. The Coalition then went much further to also focus on issues pertaining to the upper division curriculum, interdisciplinary student exposure, embedding technologies into the educational process, faculty and student professional development as it pertains to the educational process of how students learn and how faculty teach (rather than just the issues of content), the special concerns to increase the percentage of underrepresented minorities among engineering graduates, and an extensive organised assessment programme.

These initiatives were then followed with the establishment of those processes required for the implementation of earlier innovations, institutionalisation of these and the development of the culture change to permit them to become sustainable. While this has been a successful initiative, further initiatives to address the need for programme flexibility and the technological awareness education of a wider segment of the citizenry has not yet materialised.

OUTCOMES AND CULTURE CHANGE

At the heart of any educational enterprise are the interrelationships between how we organise and structure the enterprise to establish the best environment, what we teach and how we teach. The Gateway Coalition fostered significant organisational and structure change, which has brought engineering up-front into the freshman year. Since the Coalition's inception in 1992, there has been a continual increase in the number of freshman students who participate in experimental design to the point where it is currently the standard for the entire freshman class of almost all partner schools (see Figure 1). This, together with the integration of the humanities and the sciences into engineering core issues that the programmes address, has brought an immediate sense of application and context to the mathematics and science basics.

This changing educational environment is further enhanced by the renewed dedication of senior faculty to undergraduate engineering education. Compared to 1992, the number of tenured and tenure track engineering faculty teaching freshman and sophomores, where the retention issues are most acute, has increased from slightly more than one-fifth of the faculty to more than one-half, while the number of senior faculty so involved has increased from a small number to one-third of the faculty.

The number of interdisciplinary courses has also increased greatly and the number of student active contacts with engineering courses that embed the issues of communication skills and engineering ethics has increased 12-fold. Students and faculty have worked in teams across institutional boundaries in such programmes as concurrent engineering. As an example, one project of this programme involved students from five geographically dispersed schools working on the design and production of a feeding device for a quadriplegic individual. Students conferred via all forms of telecommunications, including video. After agreeing

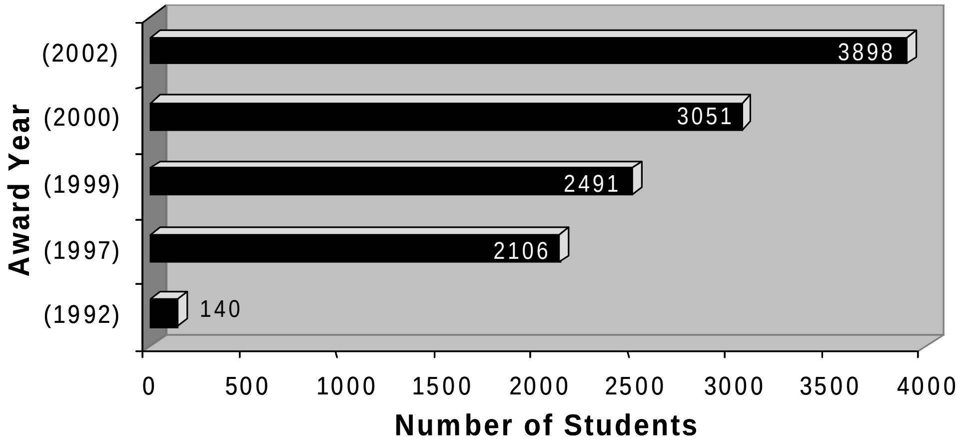

Figure 1: Number of students participating in freshman design.

on the basic design, each group worked on a specific segment and ultimately all components fitted together to provide a completed system (see Figure 2). In this manner, students worked in an environment similar to that which they might encounter in a multinational corporation.

While an underlying premise of the Coalition was improved retention of all entering students, there was also specific emphasis placed on an increased retention and graduation rate for those populations traditionally underrepresented in engineering. In AY2000/2001 the Gateway Engineering Education Coalition percentage of undergraduate engineering degrees that were awarded by the partner institutions to women was 46% more, to African Americans was 118% more, and to Hispanic students 65% more than in AY 1991/92; the benchmark year prior to the initiation of the Coalition. The total number of undergraduate engineering degrees awarded was 12.7% greater when compared to the same benchmark year. Figure 3 illustrates a comparison of first to second year retention in the Gateway Coalition schools, as compared to a national study of 175 institutions providing degrees in Science, Technology, Engineering or Mathematics (STEM), as reported by the Consortium for Student Retention Data Exchange (CSRDE).

The Gateway Coalition schools fare very favourably in this comparison. In the face of generally declining enrolments nationally, the Coalition has thus contributed to the objective of an increased pool of the technological workforce and has done so in a manner to include the important shift of bringing greater percentages of women and underrepresented minorities into that workforce. Embedded in that outcome are practices which lead to greater sustained interest, enjoyment of learning, breadth of educational experience and satisfaction by the student in the educational process as well as changes among the faculty; all of which lead to the improved retention and graduation statistics.

The concept of what constitutes scholarship among engineering faculty is also changing. The number of educationally oriented publications or presentations that has been tracked by the faculty of Coalition schools has increased more than six-fold per year from the time of formation of the Coalition to last year.

There is also a major revision in the understanding for the need and value of outcomes assessment at

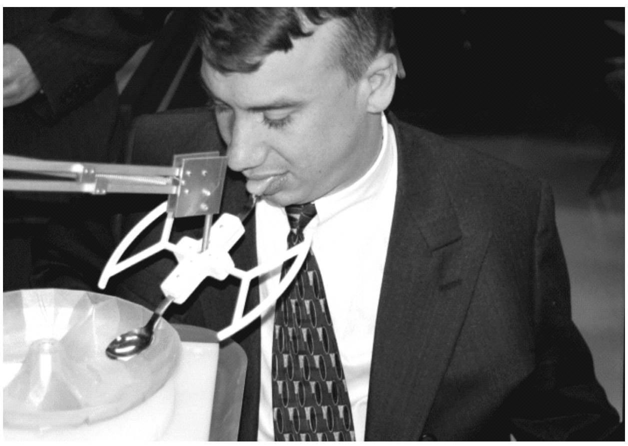

Figure 2: Feeder for paraplegics.

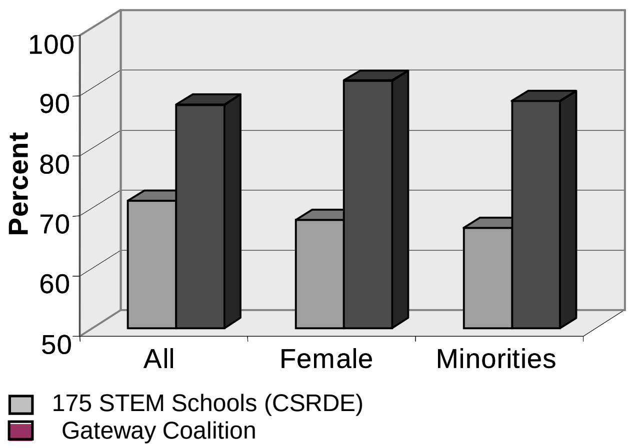

Figure 3: First to second year retention comparison.

different levels of the educational programme. All schools within the Coalition have implemented formal course and faculty evaluation systems [5]. These evaluation systems, some of which are electronically based, involve student responses and feedback to faculty and departments in order to encourage continuous adjustments and improvements. These systems begin with a clear definition of course objectives and expected outcomes for each course, which are provided to the students at the beginning of a course, and continue with student responses of the degree to which they believe those objectives have been met. This process was previously essentially non-existent in engineering education programmes but has become a sustained embedded process at all Gateway Coalition schools of engineering. Collectively, the efforts in these multiple focus areas have evolved a significant and sustainable change in the fabric of the educational culture.

A great deal of the Coalition's dissemination efforts has focused on interactive workshops, the creation and distribution of digital media and the Gateway Web Repository [6]. The products of this work, including downloadable educational modules, are freely available to all who have Internet access.

A LOOK TO THE FUTURE

Hypothesising about the future can be both interesting and provocative. Some elements of opportunity and challenge are becoming evident, while others are conjecture for us to ponder and build upon with our engineering creativity.

Changes in the educational environment for a college of engineering can be envisioned in at least two aspects. One will be in changes of the educational process for engineering students, and the other will be in a college's broader role within the university. Given the centrality of technology in every day life of the general populace, it would seem appropriate for colleges of engineering to have a central role in the broader education of all students, not just engineering students.

The educational programme of engineering students in the years ahead should incorporate more cross-institutional and global linkages. Important components that add to the holistic experience and excitement will be further integrated into the educational process. One example is the Gateway Coalition's *Globetech* technology management simulation programme initiated at the Cooper Union, one of the Gateway partner institutions. GlobeTech's objective is to familiarise engineering students with the real and very complex political, economic, social, financial, as well as technical issues that influence global technology decisions, thus better preparing them for a future of increased globalisation. The primary learning tool is an international joint-venture project negotiation Internet-based simulation.

At the same time that the programmes will become more intellectually broadening, they will also become more technically intensive. However, this will need to be achieved through a creative use of new approaches and new tools so as to enable a more time and educationally efficient environment. We cannot simply add aspects to the educational programme without finding the means to incorporate the important issues within the basic framework.

The tools will, for the most part, be information technology-based, as well as the expanding opportunities in use of the *information highway*. All will serve the broad purpose of enriching the educational experience of students generally (not just engineers) or the general public. Consider the possibilities of remote access to experimental facilities with direct feedback of the senses as the student or practicing engineer performs an operation remotely. Thus, the ability to effectively provide a fully functioning engineering education programme will permit a host of new approaches for the educational systems. Beyond that, consider, for example, computer-based modules in which pop-up or drop-down menus are available to delve deeper into the social, historical or economic relational topics of a technical matter. The emerging professionals will then better understand how to function in a world of geographically dispersed 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.

Consider a series of specialised Web repositories that serve as content seeds for a digital library environment. One example of such possible specialised seeds might be the Gateway Coalition's repository of functional educational materials that can be drawn upon by anyone worldwide with access to the Internet. The content associated with individual Web repositories, be it technical, interdisciplinary, business or social sciences in orientation, will be an enabler as the digital libraries evolve to technology-mediated support centres for learning communities.

Structural changes can be anticipated beyond those already made. Undergraduate engineering educational programmes should become more flexible without the loss of needed technical strength. Undergraduate engineering programmes should ultimately recognise the broad spectrum of career interests of students and a varied set of curricular paths should be made available to meet those student objectives. More specifically, we must recognise that students who wish to use the engineering education as a path to marketing, investment banking, business leadership, entrepreneurship, design engineering, cutting edge engineering research, or a host of many other challenging careers, will want and need different sets of educational opportunities while pursuing the baccalaureate degree.

While a common core may be important, that core must be defined as a minimal set without the expectation that all students will desire – or need – the same level of mathematical or physical sciences rigour. Providing the opportunity and encouragement for students to pursue other intellectually broadening combinations with such areas as business, economics, marketing, entrepreneurship, education, or the social sciences, as well as combinations with mathematics and the physical sciences, will be attractive to more students.

The enabling structures will be many. Some combinations may suit those entering different aspects of engineering practice, some will be for those wishing to use the quantitative thinking developed as an engineering student for other non-engineering career paths, while still others will be for those pursuing careers at the cutting edge of engineering research.

However, in total, the educational system must provide flexibility that recognises multiple engineering career and personal intellectual interests, as well as a citizenry versed in an understanding of technology. The work presented in this article is merely the beginning of the revolutionary change that should take place and offer opportunities for graduates to get a formal educational and leadership start in many career paths with engineering as their underpinning. The beneficiaries will be students, the general citizenry and the engineering profession. Nevertheless, it will be a significant challenge to the engineering education community.

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BIOGRAPHY

Eli Fromm is the Roy A. Brothers University Professor, Professor of Electrical and Computer Engineering and Director of the Center for Educational Research in the College of Engineering at Drexel University, Philadelphia, USA. His formal education is in both electrical engineering and medical physiology. He has held a number of university academic leadership positions including Vice-President for Educational Research, Vice-Provost for Research and Graduate Studies, and interim Dean of the College of Engineering at Drexel. He has also held positions with the General Electric and DuPont companies, has been a staff member of the Committee on Science and Technology of the US House of Representatives as a Congressional Fellow, a Programme Director at the National Science Foundation and a Visiting Scientist with the State of Pennsylvania House of Representatives.

His many years of activities devoted to educational leadership and the engineering educational reform movement include Principal Investigator of the Drexel E^4 project and Principal Investigator/Director of the Gateway Engineering Education Coalition programme. In addition, he has been the Principal Investigator of a number of research projects in biotelemetry including the development of micro-miniature implantable and ingestible transmitters and sensors with experimental use in physiologic measurements of the reproductive, gastrointestinal and cardiovascular systems.

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