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An Enhanced Engineering Program for Freshmen and Sophomores*

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Engineering education is the foundation of the total engineering enterprise, which in turn, is the engine driving the whole economy. These facts bring considerable pressure on the undergraduate engineering curriculum to produce high quality engineering professionals within a limited time span and with multiple budgetary constraints. A large-scale innovative experiment designed to address current urgent needs involving radical changes in the first two years of the engineering curriculum, is being conducted at Drexel University. A major goal of the experiment is to produce future engineering graduates equipped with decision-making capabilities in addition to their highly advanced technical skills. The program includes the method of team teaching in several interwoven courses, Mathematical and Scientific Foundations of Engineering, and Fundamentals of Engineering along with the introduction of freshman hands-on laboratory and design experience. The new curriculum enhances communication skills and awareness to societal problems and at the same time is introducing some fun in the classroom. Preliminary data shows encouraging results and improvement in retention figures. The experiment is now being used in an extensive student recruiting campaign.

INTRODUCTION

A LARGE-SCALE innovative experiment, involving radical changes in the first half of the engineering curriculum, has been conducted at Drexel University for the past 36 months. The project entitled 'An Enhanced Educational Experience in Engineering (E^4),' is sponsored by the National Science Foundation (NSF) (E. Fromm and R. Quinn, principal investigators). A major goal of the experiment is to produce future engineering graduates equipped with decision-making capabilities in addition to their highly advanced technical skills. Introduction of hands-on laboratory experience, along with freshman design, brings both fun and the trait of synthesis to the classroom. The program also includes the method of team teaching in several interwoven courses in the areas of Mathematics and Sciencific Foundations of Engineering, Fundamentals of Engineering, and the Engineering Laboratory. The coupled problems of recruiting students into engineering (unfavorable demographics) and, once they get there, retaining them after the freshmen year, reached crisis proportions by the late 1980s [1]. Recent results of the E^4 project indicate high projected retention rates of 82%, a very encouraging sign. The experiment should now be used in designing and setting up an aggressive student recruiting campaign.

GOALS AND OBJECTIVES

Engineering education is the foundation of the total engineering enterprise, which in turn is the engine driving our economy and national security. This fact exerts a lot of pressure on the undergraduate engineering curriculum, which by many accounts has reached a point of incomprehensibility.

It is a commonly accepted notion that twenty-first century engineering graduates should be equipped with decision-making capabilities in addition to their highly advanced technical skills. They will need a strong foundation in basic sciences, mathematics, and engineering fundamentals and, more importantly, an ability to apply this knowledge to solve real problems in a complex society, by using experimental skills and design capabilities. Strong oral and written communication skills and a capacity for critical thinking will be indispensable characteristics of future graduates. A sense of social, ethical, political, and humanistic responsibilities will constitute other essential traits. An understanding of the corporate environment and business basics, and an historical and societal perspective of the impact of technology are also important attributes.

Our goal is to produce future engineering graduates with these characteristics [1].

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PROGRAM STRUCTURE

Drexel's E[4] project focuses on the first half of the curriculum which is now being delivered to a student body of 100 per class (freshman and sophomore). First, we identified the central body of knowledge and experience vital to engineering in the future, and then concentrated on the interdisciplinary and unifying aspects which are part of the first half of the curriculum. We place an emphasis starting from the freshman year on experimental methods in engineering, and their use in analysis, design, development, and manufacturing. This approach is amplified by focusing on the computer as an aid to study, an object of study, and a professional intellectual tool which has a profound impact in practice and on every facet of the engineering profession.

Drexel's curriculum spans five years and consists of twelve resident quarter terms of three months each and three co-op periods of six months each. The E[4] project concentrates on the first six resident terms, the first half of the curriculum. Concurrent changes will take place in the six upper-level resident terms in each departmental program as well as in the co-op portion of the educational experience.

In the first six resident terms three new interwoven courses are introduced: Mathematical and Scientific Foundations of Engineering (MSFE), Fundamentals of Engineering (FE), and Engineering Laboratory (EL). MSFE changes, unifies, integrates, and presents in a totally different way, the material presently contained in several courses in mathematics, physics, chemistry, and biology. FE does the same with the material presently contained in several courses in various engineering departments. EL provides significant new experiences in laboratory theory and practice. An additional central element of these changes is that all three courses contain elements of design and are intimately coupled and synchronized so that they complement and amplify one another.

The central core to this interwoven set of courses is FE, around which MSFE, EL and Design, and the writing and communicative skills evolve. In the current traditional scheme the student encounters calculus, physics, or chemistry courses, in which prerequisite fundamental principles are taught in isolation from one another and from the interesting and exciting engineering applications. Furthermore, the student is faced with multiple timetables of course demands and milestone checks, which further add to the isolated perception of the material. In the new E[4] curriculum, the lower-division student no longer faces a group of isolated individual courses in mathematics, the sciences, computer, introductory engineering, and liberal arts studies but rather a vertically integrated package that is team-developed and taught. He or she no longer has a separate calculus course, for example, with its own timetable and for which a subsequent course, such as physics, awaits his developing mathematical knowledge base before it can begin. Now each academic quarter's program is vertically integrated while the curriculum in total is built in the traditional serial fashion from one academic year to the next. This combination will provide the benefits of curricular integration while maintaining the traditional benchmarks of progress.

The problems addressed, from the outset, are of an engineering character and their solution pro-

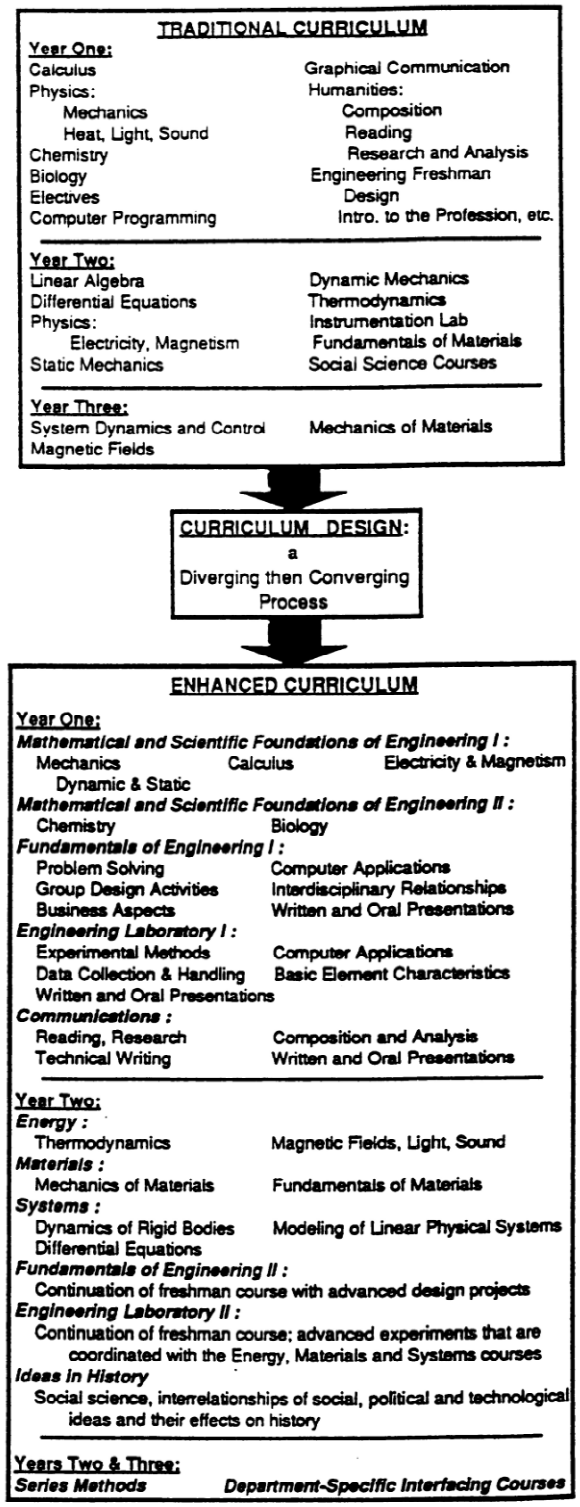

Fig. 1. The traditional versus the enhanced curriculum

ceeds by identifying and bringing problem-solving techniques to the student. The laboratory program and design projects simulate and experimentally verify the classroom facets pertaining to the engineering issue using necessary mathematical and scientific principles. This is what is referred to as a modular approach. The assembly of modules constitutes the program. The student responds to a series of intellectual exercises for which the fundamental principles and the tools to solutions are brought in and taught as appropriate. The development of these modules requires teams of faculty, educational developers, and evaluators.

The developed and packaged modules present the student with the appropriate mathematical and scientific tools, centered around the Fundamentals of Engineering (FE) core. They instill in them the inquisition, intellectual challenge and critical analysis approach. For entry into the upper division levels of content, progression in a high quality common lower division will be required before the student proceeds to the department specific orientation for his/her professional specialty and career choice.

IMPLEMENTATION PROCEDURE

Design of the modules of the new curriculum is an on-going process and the experiment is now in its third year. The PIs assigned initial work in each area to be done by interdisciplinary teams that produced the educational objectives, subject mat-

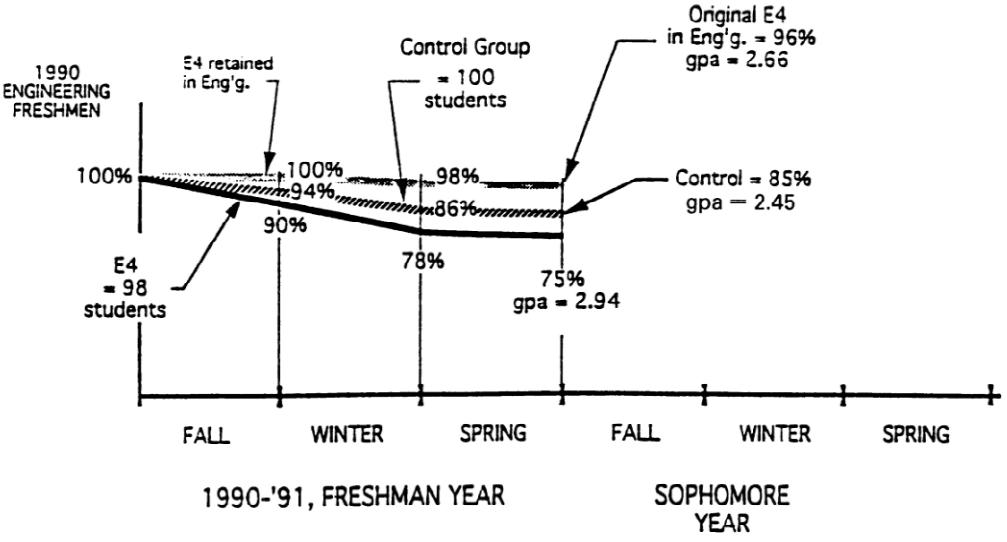

Fig. 2. Drexel College of Engineering, class of 1995.

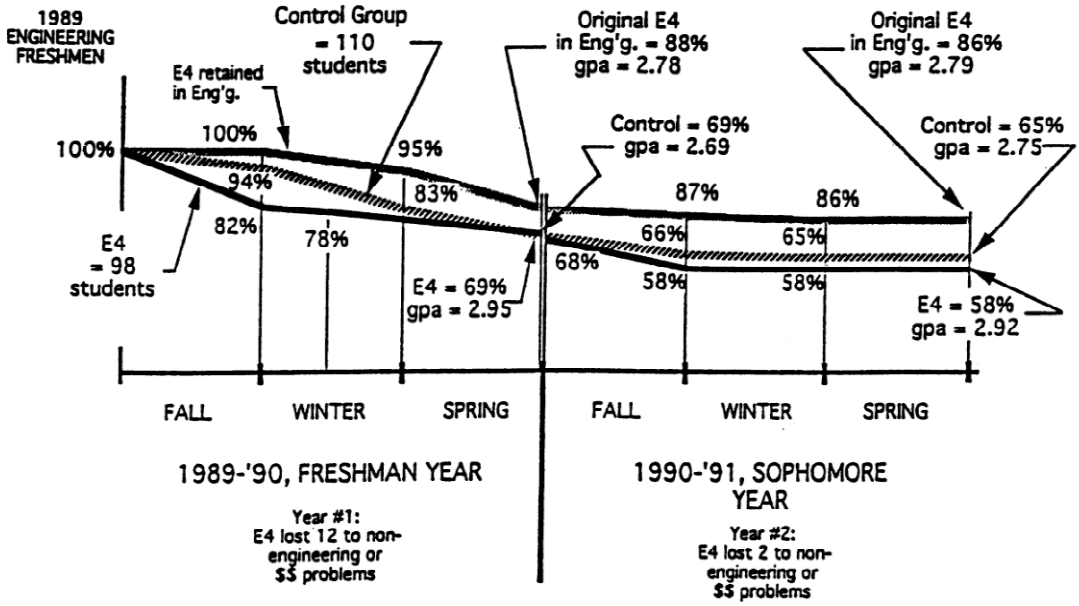

Fig. 3. Drexel College of Engineering, class of 1994.

ter outlines and sequence diagram, a list of concepts and engineering applications, and a list of laboratory experiments and instructional resources (tests, software, etc.). The course content of the first two years of the traditional versus that of the enhanced curriculum is shown in Fig. 1. In addition, the students are encouraged to work in teams and give verbal reports to their peers.

PROGRAM EVALUATION AND RESULTS

The E^4 project is being evaluated, concurrently with its development and implementation, by an internal steering committee and an external team of evaluators, while its overall performance towards its goals is monitored by an outside advisory panel made up of nationally prominent industrial and educational leaders.

Dramatic retention results can already be observed from the first two years of implementation. The same class, when compared to the control group (students who volunteered and were qualified for the E^4 program, but following the lottery did not get in) show impressive improvement.

The curves shown in Figs. 2 and 3 illustrate the comparisons between the first two E^4 classes and their control groups since entering Drexel. There is an obvious increase in the number of E^4 students who are retained in engineering (marked 'Original E^4 in Eng'g') over the number of control group students who remain in traditional engineering programs. Most of the students who leave the E^4 program enter the traditional engineering programs at Drexel, where they generally continue to make good progress toward a degree. It should be noted that the number retained in the E^4 is lower than that of the control group. The reasons that they leave E^4 are:

(1) they fail one or more of the E^4 courses and cannot continue in that program as they would lose too much time when there are no make-up courses offered. E^4 is still an experimental program with cost constraints, and the students would have to wait until the next academic year to retake the failed courses.
(2) they consider the workload in E^4 to be more than they can handle and the load cannot be reduced since there are no 'trailer sections', or repeats of the courses in the following terms, that would allow them to make adequate progress.

Data for this year's freshman class (the class of 1996) is currently very similar to that shown in Fig. 3 for last year's class.

The retention data for engineering in general, summarized in Table 1 shows a very grim statistic. At Drexel, however, the picture is not so bad in the traditional engineering curricula, and is even better for the students in the E^4 program. The data looks significantly better when one examines the relative progress of the students in the traditional programs versus those in the E^4 program. The percentage not behind in any of their courses, is dramatically better in the E^4 program.

Table 1. Student retention in engineering

NATIONAL AVERAGES

42% drop Engineering
by end of year #1 and another
23% drop engineering before graduating

As of the end of the spring term, 1990/91:

DREXEL COLLEGE OF ENGINEERING CLASS OF 1994

Control Group (Equivalent to the E^4 class):
- 18% *withdrew*;
- 7% were *dropped*;
- 11% *changed* to non-engineering;
- 29% were at least *one course behind* and
- 8% were *four or more courses behind*;
- *ONLY* 35% were *"ON TRACK"*.

E^4 Group:
- 9% *withdrew*;
- 5% *changed* to non-engineering;
- 25% *transferred* to *regular engineering* and were generally only *one or two courses behind*;
- *ALL* 58% of the E4 group were *"ON TRACK"* by the end of their sophomore year.

DREXEL COLLEGE OF ENGINEERING CLASS OF 1995

Control Group:
- 12% *withdrew*;
- 1% were *dropped*;
- 2% *changed* to non-engineering;
- 53% were at least *one course behind* and
- 11% were *four or more courses behind*;
- *ONLY* 33% were *"ON TRACK"*.

E^4 Group:
- 4% *withdrew*;
- 1% *changed* to non-engineering
- 21.4% transferred to regular engineering *only one or two courses behind*;
- *ALL* 74% of the E4 group were *"ON TRACK"*.

Numerous attitude surveys are conducted to ascertain how the students view the E^4 program, while they are in the program as well as in 'exit interviews' when they leave the program, whether voluntarily or not. In almost every case, the students really enjoy the work, particularly the team activities in recitations and labs, and the individual and team design projects that they are assigned to do nearly every term. The attitudes of the control groups are also sampled for comparison. It is clear that the E^4 students have a much better sense of

what engineering is about and why they are taking the courses given in the E^4 program. They also have a very positive attitude about themselves, about their coursework and the faculty who they see as quite helpful and interested in them. It is noteworthy that after a few terms in the E^4 program the students begin to look to themselves for reasons for not doing better, rather than blaming it on the faculty or other causes. The faculty in the E^4 program generally feel very excited about the curriculum, as well as by the motivation and quality of the students, who are not chosen for their past academic performance, but by lottery from a population of E^4 program volunteers from the entire freshman engineering class. The first year's admitted E^4 students did have a requirement that their SAT score be greater than 1100, but the following two freshmen E^4 classes had no such requirement. The faculty work more closely with the E^4 students and have come to believe that the students are much better and more motivated than previously thought when opinions were based on the students' freshman year performance in the traditional engineering program, which was mostly their performance in isolated science courses with no engineering applications. We are very encouraged by the E^4 program results and their implications on a national scale, when exported to other institutions.

REFERENCES

1. E. Fromm and R. Quinn, An Experiment to enhance the educational experience of engineering students, *Engineering Education*, April, 424–429 (1989).
2. *A National Action Agenda for Engineering Education*, Report of the Task Force on a National Action Agenda for Engineering Education, Washington, DC: ASEE (1987).
3. D. H. Thomas and A. Lawley, Drexel's E^4 Project: an enhanced educational experience in engineering, *Journal of Materials*, March, 32–37 (1991).

Dr Shlomo Carmi is currently Professor and Head of the Mechanical Engineering and Mechanics (MEM) Department at Drexel University, Philadelphia. He received his Ph.D. and M.S. degrees in Aeronautical Engineering at the University of Minnesota, in 1968 and 1966, respectively, and his B.S. degree (Cum Laude), in Mineral Engineering from the University of Witwaterstand, Johannesburg, South Africa in 1962.

Prior to joining Drexel University in 1986, he served for 18 years on the faculty of Wayne State University (WSU), Detroit, Michigan as Professor, 1978–1986, Associate Professor, 1973–78 and Assistant Professor (1968–73). During his 1985/86 sabbatical Dr Carmi was a Congressional Fellow (ESD) working as Science and Technology advisor for US Senator Carl Levin (D-Michigan) in Washington, DC and during his 1977/78 sabbatical he was appointed Visiting Professor—I. Taylor Chair in the Mechanical Engineering Department, Technion, Haifa, Israel. Other professional experiences include: Senior Lecturer at the Aeronautical Engineering and Applied Mathematics Departments, also at the Technion (leave of absence from WSU) 1970–1972; Special Research Staff, Detroit Edison Company, Detroit, Michigan, Summer 1983; Research Specialist, Ford Motor Company, Dearborn, Michigan during the summers of 1973, 1974, 1975, 1977; Research Engineer, West Rand Gold Mining Company, Krugersdorp, South Africa, 1962–1963; as well as consulting for various companies.

Dr Carmi has published over 40 refereed papers in scientific journals and has made numerous presentations at universities, government agencies, industries and professional societies meetings. His main research interests include hydrodynamic stability of fluid flows, transition to turbulence, time-dependent and non-Newtonian fluid flow, heat transfer, bifurcation and chaos, using numerical methods in computer simulations. Dr Carmi is a Fellow of ASME, is a recipient of many honors and awards, and his research is funded by DOE, NSF, ARO and industry. He was Associate Editor of the *Journal of Fluids Engineering* (Transactions ASME) and is currently an ABET evaluator, Mechanical Engineering program—ASME. Dr Carmi serves on numerous university and ASME committees and panels, regularly organizes and chairs sessions for meetings and referees papers and research proposals for NSF and other agencies.

Dr Thomas received his BSME and MSME degrees from Drexel University in 1956 and 1959, respectively, and his Ph.D. in Engineering Design from Case Institute of Technology in 1965. He joined Drexel University's Mechanical Engineering faculty in 1956. His Ph.D. research at Case's Engineering Design Center under the direction of Dr James Reswick, focused on the biomechanics of the human hand and finger.

Currently Dr Thomas is involved in innovative teaching methods and curriculum design; more specifically, he is a principal faculty member in the E^4 Project (an Enhanced Educational Experience for Engineers) that is examining a proposed restructuring of the first two years of the engineering curriculum under the sponsorship of the National Science Foundation.

Dr Thomas's other research and teaching interests include design engineering, system dynamics and control, computer-aided drafting and design, and biomechanics. He also actively consults in the areas of product safety and liability, human factors, accident reconstruction, machine design, and vehicle dynamics.

Dr Tsou received his M.S. degree in Mechanical Engineering from the University of Toronto in 1958 and his Ph.D. degree from the University of Minnesota in 1965. He joined the Mechanical Engineering and Mechanics Department, Drexel University in the same year, where he has been an Assistant Professor, Associate Professor and Professor in the MEM Department.

Dr Tsou is currently a Research Professor and a Fellow of ASME. His main research is in the heat transfer area where he performed pioneering research in the heat transfer of moving surfaces. Dr Tsou was the first to establish that the boundary layer theory is useful for describing these complex phenomena. In the film cooling of gas turbines, his work led to effective cooling of turbine blades through innovative design of injection slots. He developed the concept of ablative cooling for gun barrels, and formulated a theory that successfully describes this method. Dr Tsou paved the way for a highly successful and visible US–China cooperative research program in heat transfer, and helped create effective professional linkages between researchers in the two countries. Through his efforts, heat transfer became the first engineering discipline to be formally accepted in the science and technology agreement between the US and China. This brought about new funding that benefited members of the heat transfer community of both countries. Four years ago, Dr Tsou directed his effort toward the initiation of joint research in space applications with Taiwan, which highly increased the various research activities at several universities in both the east and the west.