IMPLEMENTING CHANGES IN ENGINEERING EDUCATION*

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INTRODUCTION

I believe the world really does face a series of crises of immense proportions if it continues the policies, practices and attitudes of the past. People who know most about these crises seem also to be the most concerned. For example, Secretary General U Thant recently stated:

> **"I do not wish to seem overdramatic but I can only conclude from the information that is available to me as Secretary General that the members of the United Nations have perhaps ten years left in which to subordinate their ancient quarrels and launch a global partnership to curb the arms race, to improve the human environment, to defuse the population explosion and to supply the required momentum to development efforts. If such a global partnership is not forged within the next decade, then I very much fear that the problems I have mentioned will have reached such staggering proportions that they will be beyond our capacity to control."**

The crises we face are not sudden calamities which characterized most crises of the past. Today's crises have been creeping up on us for some time. They are upon us because of accumulations of millions of separate actions, not one of which by itself is particularly harmful. Today's crises are difficult to comprehend because they are not completely evident to a person standing in one place at one time. Their comprehension requires some depth of understanding not only of present events at remote places, but of the probable effects of continuation of present trends into remote times. There is no way of knowing if man will be able to cope with the problems described by U Thant, but we must try just as hard as we did when we met the challenge of physical attack back in 1941.

In order to solve the problems of our natural and man-made environments, we need a great deal of detailed information about them. Many scientists and engineers have been collecting and interpreting such information for the general public. It is encouraging that this has resulted in some political action which has led to more detailed attempts to gather data and to some environmental improvement programs. Unfortunately, present actions are generally far too modest to be more than a beginning. We see, however, that they are expanding and creating many needs for trained people.

To solve our environment problems, we need not less technology as some have suggested. We need instead a much more sophisticated technology. By comparison, the technology of the past has been somewhat like a bull in a China shop, charging ahead to achieve its objective with too little regard for its effects on the surroundings. Engineers of tomorrow must tiptoe through the China shop; they must design systems which are humanizing rather than dehumanizing, which bend to meet real needs of people rather than forcing people to bend to the needs of relatively crude machines. To do this requires a new kind of engineer. One much more sensitive to the delicate ecological balances of nature, to the finiteness of resources, and to social and psychological needs of people.

One place to start is with undergraduate engineering education. We need to examine its relevance to the needs of the 70's and 80's. This process has been underway at the University of Minnesota for several years, and at the present time we are in the process of implementing

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changes which have been recommended by an Engineering Programs Study Committee. In this paper, the major conclusions of this Committee will be presented and some of the processes underway for implementing desired changes will be described.

MECHANISMS FOR IMPLEMENTING CHANGE

During the Summer of 1968, the Dean of the Institute of Technology at the University of Minnesota formed an Engineering Programs Study Committee. Working over a year and a half under a foundation grant, the Committee produced a document entitled "Education of the Engineer," which, through inputs for students, faculty and professional engineers, critically examines engineering education at the University of Minnesota and gives a series of recommendations for change.

The changes in the undergraduate program have been under the general supervision of a Director of Undergraduate Studies. Because of the special needs of the Lower Division, a Committee on Lower Division Engineering Programs was formed. The first task of this Committee was to condense from the volume "Education of the Engineer" a succinct set of Guidelines. These are given in Appendix A and will be discussed after we discuss the rationale for the Lower Division Committee.

Lower Division Committee

Because of the increasing emphasis on research and graduate studies during the 50's and 60's, the content of Freshman and Sophomore engineering curriculum became more and more the province of Departments of Physics and Mathematics. Engineering faculty found little reward in involving themselves at that level. During the 60's the need for socially relevant education came more and more into the minds of entering students, more commonly the brighter ones. To an alarming extent, such students transferred to the social sciences although they had the aptitude to become excellent engineers. They either began to think engineering contributed to more than it solved societal problems or they simply could not see the relation between the physics and mathematics they were taking and work on the types of engineering problems they envisioned.

In appeared quite clear that immediate attention needed to be given to the Lower Division in a formal way. An appropriate mechanism for this was a Lower Committee which would supervise the Lower Division freshman engineering students, introduce experiences in environmental awareness, interdisciplinary study, independent study, and generally to carry out recommendations of the Engineering Programs Study Committee. In order to give the Committee power to influence change, it was given the authority by the Engineering Faculty to certify completion of the Lower Division. Without such authority, the Committee would have been relegated to a relatively ineffective advisory role.

In practice, the process of certification will actually simplify the administrative procedures for supervising students progress and will permit greater flexibility in student programming. The certification paper is a simple contract between the student and the Lower Division Committee through the advisor which states the courses he will complete to finish the Lower Division. The important effect of this process is that it gives authority and substance to recommendations for change agreed upon by the Lower Division Committee.

Guidelines

In order to develop criteria upon which to base certification of a student's Lower Division program and to aid in understanding of the appropriate functions of the Lower Division Committee, the Report of the Engineering Programs Study Committee was carefully analyzed to digest from it a series of operational statements which could be used as guidelines (Appendix A). These guidelines are divided into three parts: A statement of the purpose of engineering: a series of seven statements giving the desired characteristics of engineering graduates: and a series of sixteen operational statements which are guidlines for revising the structure of our engineering programs. The form of these statements has been discussed extensively by our Lower Division Committee and has been accepted by the Committee. Ample time was also allowed for comment by the entire Engineering faculty; however, few comments were received. Hopefully, this means we have a consensus. Realistically, faculty members are busy people and many would not take a document like these Guidelines seriously until they would perceive some effect on their activities.

I would like to make some comments on each of the three sections of the Guidelines. The first gives our interpretation of the purpose of engineering. Traditionally, engineers have worked to find technological solutions to problems of interest to a particular client. We augment this with a statement of responsibility to society i.e., that the engineer must as a part of his job see that the social costs and benefits of his systems are examined and taken into account. We recognize that techniques for analyzing many of the social costs and benefits are poorly developed, but that one of the responsibilities of the engineering profession must be to take the lead in seeing that appropriate methods *are* developed.

This process, called Technology Assessment, should be carried through as a normal part of every design and hence should be included in undergraduate course work in some way. At the present time, we are working on development of the technique in a broad interdisciplinary urban transportation project. As the technique develops, we hope to include it in a formal way at least in our design courses.

The second part of the Guidelines gives desired characteristics of the engineering graduate. He is a person who has acquired a working knowledge of the basic sciences and of engineering methods; he should have acquired an understanding of the setting within which he works, i.e., the cultural, historical, social and physical environment; he has learned how to draw from his store of knowledge the bits that are needed in a particular situation; how to apply the spark of creativity; how to communicate to obtain data and make his results useful; and, finally, he has learned in such a way that he can continue the process throughout his professional life.

To mold engineering students into graduates with these qualities is difficult and it will require some rather basic changes. We do a commendable job in teaching basic and engineering sciences for that has been one of the main aims of engineering education over the past ten to fifteen years. Students are, however, too accustomed to being spoon fed and too easily confused by problems which require a combination of disciplines learned in several courses. To overcome this, students should be given more open-ended design problems even though this means they will be able to cover less material in a given course. We give lip service to the philosophy that the four undergraduate years do not complete the education of an engineer and that he must expect to continue his learning process throughout his career; however, when it comes to determining course content, we still often assume tacitly that the student must have acquired certain definite bits of knowledge during his undergraduate years, and as a matter of fact, many more bits than he can absorb.

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To get students into the habit of independent study, we should require a certain amount of material in every course be learned independently without the benefit of a lecture. A great deal of undergraduate engineering could be learned this way and would leave the instructor free to spend more time on the difficult points. True, it runs contrary to habits developed by many students, but it is essential if we are to build habits whereby an engineer can continue to study on his own.

The third part of our Guidelines is a series of 16 operation statements concerning the structure of engineering programs. While these statements are difficult to classify, they recognize the need for motivation, for greater flexibility, for more options, for interdisciplinary experiences, for concentration in fields other than, but related in a broad sense, to engineering, and for the use of increased subjective judgement rather than rigid requirements.

The task of the Lower Division Committee has been to develop ways of carrying out these recommendations in the Freshman and Sophomore programs.

SPECIFIC CHANGES: PROGRESS AND PERSPECTIVES

Now I will discuss some of the specifiic actions we have taken and are taking to meet the objectives set down in our Guidelines. Here we move from theory to practice. Here the practical difficulties of budgets, student-teacher ratios, time constraints, varying departmental interests, and varying experience and orientation of individual faculty members have to be resolved. The result is that the changes we can make this year or next are not as dramatic as we would like; however, we must retain a healthy level of impatience and persistence if any worthwhile goal is to be attained.

Criteria for Lower Division Programs

The first thing we did after establishing our Guidelines was to settle on a set of criteria (Appendix B) against which to approve Lower Division programs of students and departments. These criteria were to be broad policy guides designed to permit the greatest flexibility possible individual student programs within constraints imposed by ECPD requirements, our own concept of engineering education, and other practicalities such as the fact that 50% of our upper-division student complete their lower-division work in junior colleges, state colleges and private colleges in Minnesota.

The results are 1) that the proportions of math, natural science, engineering science and liberal education are roughly unchanged, but that 2) the credit load will be reduced by 5 to 10%, 3) students will be able to change engineering majors at a later date than before without penalty, and 4) the flexibility of engineering programs will be more visible to the student. In addition, we now explicitly encourage students to take courses in ecology and in the relationship between technology and society. Finally, we require development of courses at the Freshman level to increase environmental awareness, to expose the student to conceptual design processes and to otherwise show the student how his education can lead to a constructive, socially-relevant career.

Pilot Project in Freshman Engineering

One of the ways engineering freshman have been demotivated in the past has been through the way Freshman English has been taught. This year we have conducted a pilot program involving 150 Freshman engineering students, in which the main emphasis has been on teaching English composition. But instead of taking topics from the classical literature, students have been writing themes related to environmental issues, science fiction, careers in engineering, etc. In addition, this group has been exposed to a series of lectures on various engineering subjects by carefully selected engineers from local industry. The whole effect seems thus far to be markedly, but perhaps not surprisingly, positive and will

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form the basis for the way we will conduct courses for all engineering Freshmen next year.

Engineering Faculty in Freshman Math and Physics

Another problem has been to help the Freshmen see the relevancy of his math and physics. A related problem has been to make the engineering faculty sufficiently aware of the content of these courses so that meaningful comment and change can be made. Both are being solved by recruiting engineering faculty to take recitation sessions of Freshmen math and physics. This requires a small enough portion of a faculty member's time to be feasible and seems to be a significant improvement over use of physics graduate students to teach these sessions. The main problem is to convince enough engineering faculty members to donate their time.

AN ATTEMPT AT INTEGRATIVE EDUCATION

As a final topic in innovative education, I will discuss an experimental course entitled, "Ecology, Technology and Society," which we are offering this winter quarter for the second time. The course grew out of an Honors Seminar entitled, "Technology, Man and the Future," which I was privileged to lead in the fall quarter of 1969. **The reading I did in preparation for this seminar gave me a much greater depth of awareness of the environmental crisis than I had had before. In essence, it converted me from an environmentally-concerned person into one whose entire career is now dedicated to solution of problems of the human environment.**

With the help of a small committee, I developed the outline for an interdisciplinary course which would treat what we judged to be the most critical environmental problems of the coming decade. The outline began with a series of lectures on the philosophy of integrative education, the history of environmental concern and the ecological basis of life on earth. We then considered subjects such as resource limitations; national priorities; air, water and ground pollution; electric power, food production and its environmental effects; population growth and control. With this background, we turned to the social sciences. He we considered the relationship between environmental issues and the possibilities of relief through legal and governmental means, and we considered economic problems of a recognizably finite earth. Finally, we considered the meaning of all that preceded for human volues.

After developing the outline and limiting the scope of our considerations, we made a careful selection of lecturers. The aim here was not only to present the student with a broad range of views but to pick faculty with genuinely-developed concerns for the environment from whatever view they approached the subject. In order not to encroach too deeply on faculty time, no lecturer was asked to give more than two lectures and most gave only one. As a matter of principle, none of the lecturers is directly compensated but joins us because of genuine interest and concern.

The question is now whether this is an *inter*-disciplinary course or whether it is merely *multi*-disciplinary. The latter is a lecture series—the former is much more. We want to do more than just expose students to a collection of environmentally relevant topics, however admirable that goal may be. To attempt to make the course interdisciplinary, we do the following:

- We brief each lecturer in detail on the purposes of the entire course and the content of the other lecturers and we ask each lecturer to try as well as he can to relate his material to the course as a whole.
- We ask each lecturer to provide a series of questions on his topic and its relation to other topics in the series. These questions are distributed to all lecturers and to the class at the beginning of the quarter. The students are told that these questions will form the basis for the final exam.
- We divide the class into student-led discussion groups of 10-15 students each. They choose their own time and place to meet and try to work out responses to the study questions.
- The moderator and teaching assistant attend all sessions and try to help relate the various topics in introductory comments.
- We brief the class at the first lecture on the history and importance of integrative thought.
- Finally, we remind the student that true integrative education comes finally in the individual mind to the degree that that mind contemplates the relationships between various inputs. Careful selection of discussion questions aids this process greatly.

At the end of the spring quarter last year, we asked the students to give reactions to the course. These reactions have made wonderfully inspiring reading. Many students said the course was the best they had ever taken, that they devoted a great deal more time to it compared to other courses of comparable length, that they liked the idea of hearing many different lecturers in one course. The latter was gratifying in terms of one of the motives in using many lecturers. With concerned faculty, we felt each would put more effort into his lecture than he would into each of the lectures he would give in an extended series.

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An indication this quarter of students interest in the course is the following: *We reserve the lecture hall for the hour following the lecture and invite the class to stay on an optional basis to question the lecturer. In almost evxery period, nearly the full class remains the full optional hour.*

The course has attracted a great deal of attention in the Twin Cities, and in the state, e.g., whe have had many calls inviting various of the lecturers to speak, and the course is taped and carried over the University of Minnesota radio station. A number of people take the course for credit via the radio and the comments we have received are most gratifying. It is clearly evident we are serving a real need.

CONCLUSIONS

By way of concluding remarks, I would like to offer the following:

Continued life on this planet in any sense meaningful to us today is going to require a much more sophisticated form of engineering than we have practiced in the past. The engineer needs to develop real understanding of and concern for the physical environment and he needs to learn to humanize his technology to a much greater extent than in the past.

These qualities must be impressed upon the engineering student during his undergraduate years in ways that will stick with him. Doing this will require persistent, painstaking efforts involving education of both faculty and students. Direct proof of the appropriateness of recommended changes usually can come only over a period of many years. It, therefore, appears that the collective wisdom of enlightened and concerned engineering faculties is one of the primary keys to successful resolution of the environmental crises.

APPENDIX A

Guidelines* For the Committee for Lower Division Programs in Engineering, Institute of Technology, University of Minnesota.

I. The Purpose of Engineering

The central purpose of engineering is to pursue solutions to technological problems in order to satisfy needs and desires of society.

In pursuing solutions to technological problems, the engineering profession is responsible not only for the technical performance of systems devised and for needs and desires of users, but for identification of the social costs of these systems and for development and use of procedures whereby these costs will be accounted for in ways which will be fair and equitable to all affected parties.

II. Desired Characteristics of Engineering Graduates

1. Engineering graduates should be sufficiently grounded in chemistry, physics, and mathematics so that they can apply them to the solution of engineering problems in a chosen field of specialization.
2. Engineering graduates should understand the physical, mathematical and computational processes by which constrained optimum solutions to engineering problems are found and should be able to participate in the solution of such problems.
3. Engineering graduates should have an appreciation for and be sentitive to the broad societal, economic and physical environments within which they live and work and to the impacts major technological systems have had on these environments and on human values.
4. Engineering graduates should be able to perceive their technical, social and humanistic education as an integrated whole.
5. Engineering graduates should understand the role of creativity and innovation in solution of engineering problems from first-hand experience.
6. Engineering graduates should be able to perceive their technical ideas and concepts verbally, graphically and mathematically.
7. Engineering graduates should have developed study habits which will enable them to continue independently to extend the scope of their knowledge, and should have developed an appreciation for the significance of the limited scope of the knowledge they possess.

III. The Structure of Engineering Programs

1. Engineering programs should be designed so that the above characteristics are developed continously rather than in discrete time blocks.
2. All of the characteristics listed in II should be present to some degree in every engineer! however; because of varying individual motivations, societal needs and human limitations, many alternative engineering programs should be provided with somewhat different objective but with each containing a minimal content common to all.
3. The programs and courses should be designed with recognition that some students are motivated toward careers in engineering science, others toward professional engineering activities, and still others toward engineering careers which maximize social interaction.
4. To allow the student sufficient time to establish his interests, some programs should be designed so that he can delay his choice of department major to the greatest degree possible consistent with other objectives, desirably to the third quarter of the sophomore year.
5. Courses should be developed to introduce students to engineering at the freshman and sophomore level. These courses should acquaint the student with processes of creative synthesis and should motivate freshman engineers to a more intelligent commitment to their disciplines.
6. Engineering programs should be constructed to permit students freedom to explore a number of fields within a given engineering discipline but require them to examine engineering methods in some depth using at least one field as an example.
7. In the social and humanistic areas, students should be provided with broad options rather than prescribed sets of courses.
8. Both laboratory and design courses should be offered on an elective basis, above and beyond basic requirements, and strong efforts should be made to recruit faculty to teach them.
9. Practice in written communication should be made a part of upper-division engineering courses. For example, in cooperation with the English and Journalism Departments, reports could be required which would be corrected and commented upon by these departments.
10. Interdisciplinary engineering programs, some with heavy involvement in the socio-humanistic areas, should be encouraged as optional paths when the objectives are well developed and viable and the substantive course content is available.
11. All one-quarter courses offered by I.T. which are not exclusively for graduate students should normally have a minimum of four credits, except for those primarily for freshmen; these should normally have a minimum of five credits. Exceptions to these guidelines should be carefully reviewed.
12. The time required for the average student to complete the work of a course should be about thirty total hours per quarter credit.
13. To assist the student in allocating his efforts, he should be provided with a guide to the way most students would be expected to divide their time among the various activities required by each course.
14. If an individual Upper Division student so desires, he should have an opportunity to concentrate his efforts to the extent that a full quarter of fifteen credits could be devoted to one project or one subject of instruction.
15. To the extent practical, subjective judgment by faculty and students should be favored over rigid requirements for admission, for entrance into specific courses, or for degrees.
16. The premise that the need for personal advice and counsel is the greatest need of all engineering education should be given formal recognition.

*Digested from The Report of the Engineering Programs Study Committee, January 1970.

APPENDIX B

CRITERIA FOR LOWER DIVISION PROGRAMS IN ENGINEERING AT THE UNIVERSITY OM MINNESOTA

A student will be certified to have completed the Lower Division if he receives the recommendation of the LDC Department Representative of the department in which he wishes to pursue Upper Division work and the concurrence of the Lower Division Committee. The student has the right to appeal the decision of the Department Representative to the full committee by request to its Chairman.

A Lower Division Program submitted by a student is to receive the Department Representative's recommendation for approval if in his judgment it shows evidence that the student has acquired the knowledge normally possessed by students who have completed programs which are included within the framework outlined below. It is up to the discretion of the Department Representative, subject to appeal to the full committee, to determine the type of evidence upon which the recommendation is to be based.

1. Liberal Education. The student is to have completed approximately half of Liberal Education requirement established by the Institute of Technology in accordance with the all-University policy on liberal education. Only in unusual cases would the program have deviated by more than one course from the half-way point, i.e., from *18* credits.*

2. Mathematics. Normally the student would have been expected to have completed *23* credits of calculus-level mathematics up to and including an introduction to differential equations. With reasonable cause, and with the concurrence of the department the student wishes to enter, the fifth math course may be replaced by a discipline-oriented math course, e. g., statistics. This option is not available to the undecided student.

3. Natural Science. The student is to have completed 12 credits in calculus-level physics; 4 credits in chemistry; and 4 additional credits in either physics, chemistry, biology, geology, ecology, or some other natural sciences. The first 16 of these credits are exclusive of laboratory.

4. Engineering Science. Each engineering department program is to include at least two engineering science courses or *8* credits from the five options: mechanics, electric circuits, fluid mechanics, thermodynamics, and materials. In order to minimize the problem of transfers between departments, it is suggested that the department programs recommend a third course in either engineering science or natural science. The undecided student is to have completed at least three 4-credit courses or *12* credits from at least three of the above five options.

5. Laboratory. A minimum of 4 credits in observational and manipulatory laboratory work must be completed in the Lower Division.

6. Introduction to Engineering. Normally this will include *6* credits of work in engineering orientation, motivation, elementary problem solving, and conceptual design; evironmental awareness; computer programming; and engineering graphics, split approximately equally among these four subject areas.

At least 90 equivalent credits are required to complete the Lower Division.

If a student's program deviates by more than two courses from the program recommended by his prospective major, he would be expected to make up this difference as part of his Lower Division Program. The first two make-up courses would be taken as a part of the student's Upper Division program. A department program will be within the spirit of these criteria if it will permit a student to transfer to another department with only two make-up courses.

* Quarter credits. One quarter credit is expected to require a total of three hours per week.

BOOK REVIEW (Cont'd from p. 73)

probability, statistical mechanics and quantum mechanics and then give a few common illustrations: molecular velocity distribution in a gas, specific heat of a Debye solid, electron gas in a metal.

As in the earlier parts of their book, the authors write clearly and succinctly but their conviction and authority are now notably lower. Whereas the utility and power of classical thermodynamics were evident throughout, it is not at all apparent to the reader where all this statistical material is going to lead in the sense of engineering application. The intellectual beauty of statistical thermodynamics is nicely conveyed but the engineering student who wants to see practical results will be disappointed. The chapter on quantum mechanics is probably too difficult for undergraduates who have not had a strong course in physical chemistry or atomic physics.

This text is admirably suited for a one-year thermodynamics course for general engineering students in their third (or possibly even their second) college year. It is likely that students will react warmly to this text because, unlike so many other books, it was written to meet student needs rather than to show off the authors' erudition, to practice pedagogy rather than to portray the authors' particular research accomplishments. Professors Sonntag and Van Wylen are to be congratulated for having produced a major contribution to undergraduate engineering education; their book deserves, and no doubt will achieve, wide adoption. However, for chemical engineering students it will be necessary to supplement this book with another one, suitable for undergraduates dealing with the equilibrium properties of mixtures. That book, unfortunately, remains to be written.

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