Engineering Education 2001

The Neaman Press

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THE NEAMAN PRESS
HAIFA, ISRAEL

Printed in Israel by Freund Publishing House Ltd.

Published by the NEAMAN PRESS, Technion City, Haifa 32000, Israel.

PREFACE

The Technion – Israel Institute of Technology requested in 1983 the S. Neaman Institute for Advanced Studies in Science and Technology at the Technion, to undertake a basic study on the future of engineering education. Consequently, a committee of Technion professors was jointly appointed by the Technion and the S. Neaman Institute.

The task of the committee was to take a fresh critical look at present engineering education at the Technion and recommend changes to better meet future needs. There were no constraints imposed on the committee. All academic aspects of the educational process were open to reexamination. The conclusions in the report call for significant changes in engineering education. Some of these are specific to the Technion, others apply to the general issue. At the Technion, the report represents not the conclusion, but rather the beginning of a process of deliberations by the faculty on the ideas, analysis, and recommendations presented in this report.

The committee has met with many members of the faculty and with groups of leading engineers in industry. These discussions were most helpful, and members of the committee wish to express their thanks and appreciation to all those who paticipated in these meetings. The committee wishes also to thank the members of the Academic Development Committee of the Technion Board of Governors, Professors M. Chaikin, A.H. Shapiro, S.D. Shapiro, H.J. Simon and L.D. Smullin for their enthusiastic support of this project. Special thanks are due to Professor Y. Eckstein, the Former Vice President for Development of the Technion, and Professor G. Hetsroni, Former Director of the Samuel Neaman Institute, for initiating the project, and to Professor J. Singer, Former Technion President and Dr. M. W. Reis, President of the Technion, for the unconditional support of this project.

Members of the committee also wish to acknowledge the contribution of

Professor Y. Ziv, a former member and first chairman of this committee who resigned upon his appointment to head the Israeli Higher Education Planning and Grants Committee.

Toward the conclusion of the committee's work, an international workshop was convened in December 1986 at the Technion, in which leading educators from top technological universities from the United States, Europe, Australia and New Zealand, deliberated for three days on the many outstanding issues in engineering education. This workshop, coordinated by Professor P. Singer, provided an excellent exchange of ideas, and the committee wishes to thank all participants for their help, ideas and recommendations. Proceedings of the first S. Neaman Institute International Workshop are published separately and will be followed by additional workshops on specific issues in engineering education.

Finally, one member of the Committee (Z. Tadmor) wishes to thank Professor L. Pollara (Stevens Institute of Technology) for the many stimulating discussions on engineering education, and the Committee wishes to thank Mrs. R. Rivkind, the Samuel Neaman Institute secretary, for her patient and professional work in typing and retyping manuscripts, and for her help in organizing the workshop.

Zehev Tadmor, Chairman
Zvi Kohavi
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David Kohn

Haifa, May 1987

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EXECUTIVE SUMMARY

The Science Revolution in Engineering Education

Engineering education, throughout most of this century, has been undergoing a fundamental transformation as a result of the permeation of the natural sciences into the engineering curriculum and engineering practices. This "science revolution" brought about a movement toward teaching all-embracing fundamental principles rather than existing engineering procedures and technologies. It has triggered the proliferation of engineering disciplines, substantially increased the teaching of natural sciences and mathematics to engineering students, and above all, brought about the formulation of the engineering sciences into teachable bodies of knowledge, by the engineering faculty. These engineering sciences form the core of most engineering curricula today.

At the same time, the engineering curricula were purged of most heuristic vocational design courses, leaving a gap in engineering education to be filled during the practice of engineering. But since design, or engineering synthesis, is engineering's most characteristic feature, the formulation of design into a "hard" formalized and teachable body of knowledge remains an open challenge to engineering faculty. The intimate though complex interaction between science and technology, as well as the forthcoming vast potential of computer technology, should catalyze this process.

The movement toward the natural sciences – toward teaching fundamentals and the formulation and structuring of engineering sciences into teachable bodies of knowledge – reformed engineering education, expanded its capability, and made it possible to sustain an ongoing technological revolution for decades. Without doubt, it is the only sensible, firm guideline for the future. Therefore, it is expected that the movement will continue well into the 21st century.

The Computer Technology Revolution in Engineering Education

Parallel to the ongoing "science revolution" in engineering education and practices, a new revolutionary process brought about by the computer technology, has started. The term "computer technology" refers variously to computers of increasing capability and decreasing cost, interactive computer systems, exponentially increasing software capabilities, expert systems, artificial intelligence, computer graphics, vast, easily accessible data bases and global network communication.

The implications and consequences of the computer revolution, which might reach maturity in the 21st century, on engineering practices and education will be no less significant than those brought about by the science revolution in the 20th century.

The new computer revolution fires up and further boosts the science revolution. It provides powerful tools to further expand the scope of the engineering sciences, permits engineers to treat quantitatively an ever-increasing scope of "real" problems with all their complexities, frees the engineer from the drudgery of computation and allows time for thinking, abstraction and generalization, and thus, hopefully, for the formulation of engineering design into a "science".

The immediate consequences of computer technology on engineering education are the need to devote sufficient time to teach relevant computer-related skills, to teach engineering sciences in even greater depth, to reevaluate the contents of mathematics taught to engineering students, and to incorporate into the curriculum computer aided design courses.

Technology and Society

Technology has emerged as a dominant factor in determining the nature of society; therefore, humanists must study technology to understand social change, and engineers must study humanities to appreciate the complex interaction between society and the technology they help create. A strong background in humanities and social sciences also helps the engineer to better cope with changing social, economic, and political conditions. The present practice of teaching humanities and social sciences at the Technion and at most other engineering schools, which consists of a random selection of a few courses, from a "cafeteria of courses," should be replaced by a well-designed program of a few integrated courses in civilization, culture, technology and ethics, and similar subjects.

Communication Skills and the English Language

In addition to needing a solid grasp of natural sciences, of engineering sciences, mathematics and computer oriented skills, some training in humanities and an understanding of design, future engineers also need a number of additional skills to make them competent professionals. These include verbal and written communication, a solid mastery of the English language, basic understanding of economics and some grasp of managerial techniques and principles. Whereas the training for communication skills and the mastery of English should start well before university, and should be strongly stressed in undergraduate studies, the committee recommends that due to time constraints, management-related subjects and economics should be postponed until graduate or postgraduate studies.

Interdisciplinary Exposure

New technologies are causing a blurring of the boundaries between engineering functions. They are multidisciplinary in nature as are virtually all large engineering projects. Successful operation within the new technologies requires, therefore, some interdisciplinary exposure of students.

Future Curricular Requirements

The committee recommends the following additions and changes in the engineering curriculum:

1. Mathematics

There is a need for broadening the mathematical base in engineering education, emphasizing subjects such as numerical methods, approximate methods, finite mathematics, non-linear analysis, asymptotic methods, and mathematical principles of graphics. This need is brought about by advances in engineering sciences and computer technology. The committee feels that such subjects should be part and parcel of future engineering education even at the expense of the present, more classical mathematical requirements.

2. Natural Sciences

There is a fast growing body of knowledge in the natural sciences that engineering students must learn because future technologies will be based on a broader spectrum of scientific disciplines. In teaching physics and chemistry, emphasis should be placed on the broadening scope of the scientific base, rather than on standard subjects, some of which are taught in engineering sciences in greater depth and sophistication. Biology and natural sciences will play an increasingly significant role in future technologies.

3. Engineering Sciences

The vast amount of structured and teachable knowledge that is accumulating poses a painful dilemma of selecting and discarding subject matter for the curriculum. Computer technology continuously increases the applicable knowledge base. Therefore, the inevitable conclusion is that the share of engineering sciences in the curriculum must be continuously expanded. Moreover, in teaching both sciences and engineering sciences, the need for advanced laboratory experience cannot be overemphasized.

4. Design

There is a need to strengthen the design elements in the engineering curriculum by adding, whenever possible, courses dealing systematically with the fundamentals of design, and by incorporating in most subjects open ended problems. At the same time, archaic, empirical design courses should be eliminated from the curriculum.

5. Computer Technology

A substantial increase in computer related subjects and skills in the curriculum is needed. These include fluency in computer languages, computer graphics, data base management, familiarity with an operating system, text editing, critical evaluation of large software packages, data acquisition, some understanding of hardware elements and elements of computer control. The use of computers in the design process must become an essential part of engineering curricula.

6. Humanities and Social Sciences

It is recommended that the present system be replaced by a new program in which students will be offered a limited choice of well integrated programs. Examples of such programs are courses in civilization which integrates history, literature, art, science, technology, sociology, and philosophy, the history and philosophy of science and technology, logic, economics and social sciences.

7. The English Language

The teaching of technical English should be replaced by the teaching of the English language. Institutional requirements should be increased. Teaching of one technical course a year in English should be considered.

8. Management Skills

Management related subjects should be postponed to graduate or postgraduate studies.

9. Communication

Greater emphasis should be placed on improving students' written and oral communication skills. The introduction of a one-semester course in written and verbal communication as an institute requirement should be carefully examined.

10. Interdisciplinary Exposure

Efforts should be made to incorporate into the curriculum elements of interdisciplinary work.

Parallel to these changes, the committee recommends *reducing the overall* course load to 144 credits in a four-year curriculum which will devote 30-35% of credits to mathematics and natural sciences, 35-40% to engineering sciences, 15-20% to design and computer technology and 10% to humanities, social sciences, communication and the English language.

Clearly, most of these recommendations call for addition of subjects and skills, and in view of the already bulging four year curriculum, and the need to reduce the overall formal load on the students, their incorporation calls for substantial restructuring of the engineering curriculum.

Among the recommended changes are the following:

a. Extensive disciplinary specialization must be postponed to the graduate level.

b. The portion of elective subjects, both free electives and departmental electives, must be substantially reduced and replaced by coherent study programs clustered around major themes.
c. Honor programs for above average and highly motivated students should be introduced.
d. Teaching methods and learning habits ought to be renovated. Individual study should be strongly encouraged.
e. With the hopeful upgrading high school education, subject matters in science and mathematics should be continuously moved from university to high schools.
f. The top one third of the student body should be actively encouraged to continue studies immediately for the masters degree.

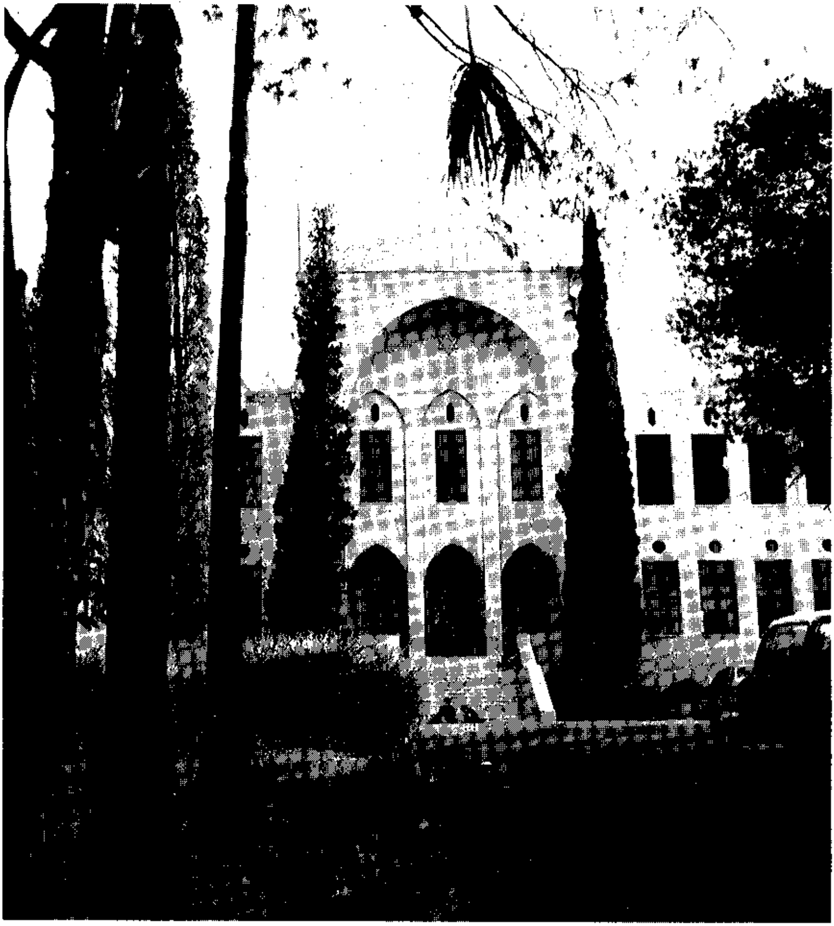
Graduate and Continuing Education

To answer future needs, the graduate school should be expanded. In addition to its classical functions, its responsibilities should also be expanded to initiate a host of interdisciplinary programs in science, engineering, and management. The programs should accomplish the following: (a) bring the student to entry level of sophisticated engineering practices; (b) bring him to the frontiers of specific technological fields, and (c) provide him with basic management skills.

Continuing education must become the accepted way of life of future engineers, and the necessity of a lifetime of education must be instilled in students. Technological universities must accept the responsibility to provide continuing education services to the engineering community.

Drive for Excellence

Although the desire for excellence is deeply ingrained in the character of academic institutions, large engineering schools face two dilemmas in their drive to achieve excellence in education. One is associated with resource allocation, and the other is the difficulty in producing excellence side by side with the ordinary. Industry needs both types of graduates and the Technion, as the major training ground of engineers in Israel, must supply both. The committee recommends that in view of the fact that Israel's future lies in high technology, and that in this field competition is global and success is possible only by matching or surpassing the very best in the world, the Technion should chart a new policy whereby emphasis on quality should be increased, and the emphasis on quantity somewhat reduced. This new philosophy ought to stress the education of the engineering elite with equal vigor to the educating of the masses of engineers who run Israel's industry and economy. In order to accomplish this it is recommended that the Technion initiate an *honors program* which will also provide the major route to encourage the top third of the students to continue their studies directly toward the masters degree and beyond. Success in this endeavor depends to a large extent on adopting the bulk of the recommendations of this committee, including the recommendation to reduce the formal load.



Technion Building – Hadar Hacarmel, Haifa
Photo: Shlomo Shoham – Photography

1. PROFILE OF THE FUTURE ENGINEER

Basic Versus Specialized Education – The 'Science Revolution'

The founding fathers of this institution have set the Technion's goals in engineering education with the following laconic statement:

> "The subject matters taught should lead to broad education rather than narrow specialization."

This statement was made in 1925(!). It still rings true today. The curriculum which appeared that year in the Technion's first catalog fully supported the educational objectives stated above. About half the classes in the three year curriculum in civil engineering were devoted to the natural and engineering sciences – a fraction which, by and large, remained surprisingly stable in the course of this century, giving much credit to the foresight and wisdom of the founding fathers.

The perception of engineering education as an education firmly rooted in the sciences, rather than being specialized, vocational and of trade school fashion, was part of a new educational philosophy that evolved at that time. One of its prominent leaders was Karl Taylor Compton, President of M.I.T., who made this the theme of his inaugural address in 1930:

> "I hope ... that increasing attention in the Institute may be given to the fundamental sciences; that they may achieve as never before the spirit and result of research; that all courses of instruction may be examined carefully to see where training in details has been unduly emphasized at the expense of the more powerful training in all-embracing fundamental principles."

The movement toward fundamental principles became the dominant trend in engineering education throughout this century. It was triggered by the phenomenal success of the natural sciences, which expanded mankind's understanding and horizons beyond all expectations. This created a desire to aply "scientific methods" to engineering and to emulate in technology the success of the natural sciences. The process gained momentum particularly after World War II, when engineering curricula were gradually purged of vocationalism and replaced by fundamental sciences. The impact of this movement has been so profound that it can be viewed as a "revolution" in engineering education. Indeed, this "science revolution" is the hallmark of engineering education in the 20th century.

It is perhaps worth noting that this trend toward a "basic" theoretical education, in contrast to a "practical," specialized one, was not limited to engineering. Hutchins (1), discussing general university education, stressed that:

> "The benefits of education are indirect. The mind is not a receptacle; information is not education. Education is what remains after the information that has been taught has been forgotten. Ideas, methods, habits of mind are the radioactive deposits left by education,"

and he goes on and claims:

> "It is now safe to say that the most practical education is the most theoretical one."

Hutchins' statements on general university education certainly sounds relevant and valid for engineering education as well.

Numerous reports, papers, panels and committees over the last few decades have expounded on basic engineering education. For example, the committee on the "Goals of Engineering Education" (2) in 1968 stated the following:

> "There has been a growing tendency to emphasize fundamentals and to provide the engineer with a basic technical knowledge that will enable him to practice in a variety of occupations."

Ten years later, the Colorado School of Mines set up a committee to define the profile of the future graduate (3). The first attribute of this frequently quoted profile was "technical competence," which the committee defined as:

> "a firm grasp of the fundamentals of mathematics, science and engineering and the ability to apply them to ones chosen specialty."

This important trend toward an education rooted in fundamentals is expected to continue in the future. Thus, the British Engineering Council Working Group (4) that studied the nature of engineers that the United Kingdom will need in the year 2010, also pinpointed "an understanding of fundamentals" as the first attribute of these future engineers. The "fundamentals," the working group says:

> "must include the relevant underlying sciences which must be *understood* not only *learnt*."

One of the most recent and comprehensive studies of engineering education in the United States, commissioned by the National Science Foundation (5), recommended that:

> "If United States engineers are to be adequately prepared to meet future technological and competitive challenges, then the undergraduate engineering curriculum must emphasize broad engineering education with strong grounding in fundamentals and science."

The need for a basic education strongly rooted in the sciences was also stressed by a distinguished group of Israeli Industry leaders in their meeting with the committee. Similar statements can be found in practically all reevaluations of engineering curricula (6, 7).

The foregoing science revolution in engineering education, coupled with the permeation of technology with sciences, had profound consequences. They triggered the proliferation of engineering into many specific disciplines, and led to the formulation of the "engineering sciences." They have brought about a gradual increase of the share of natural sciences in the curriculum, a significant widening of the mathematical foundation of engineering education, and the purging of heuristic design courses. These are discussed next.

The Formulation of Engineering Sciences

The massive introduction of the natural sciences to engineering curricula and departments led to the development of a growing list of *engineering sciences*. These are subject matters dealing with engineering systems, to which the laws of natural sciences were applied, that were researched and analyzed by the scientific method, and were *classified and formulated into commonly shared disciplines.* Examples of such disciplines in engineering sciences are electro-magnetic theory, fluid mechanics, heat transfer, reaction engineering, system engineering, transport phenomena, continuum mechanics, thermodynamics, and a host of other fields. They do not deal with any specific system, but stress the fundamental principles applicable to conditions, systems, machines and processes of special interest to engineers. Thus, the "movement towards fundamentals" in engineering consists of emphasizing both the *natural sciences* and *engineering sciences* in engineering education, while the engineering faculty has accepted the challenge and responsibility of formulating and organizing the engineering sciences into teachable bodies of knowledge. Indeed, this process occupies much of the faculty's research attention and is their major contribution. It is a monumental undertaking of great utility to industry and society. These engineering sciences form the core of the present day engineering curriculum.

The engineering community and industry accepted, of course, this movement to fundamentals in education because it was the only useful way to deal with the phenomenon of a rapidly changing technology and sudden shifts in engineering manpower demands. Studying existing technologies and existing engineering practices appeared futile because by the time of graduation, or shortly thereafter, the particular technology the student had mastered, the particular engineering practice he had exercised, may have become obsolete. The mastering of fundamentals makes the engineer adaptable to new technologies. Watt's separate condenser of the Newcomen steam engine and a nuclear reactor may represent different stages of technological evolution, but the heat transfer problems of both systems are governed by the same principles.

The formulation of engineering sciences is an ongoing process. Their scope and depth are increasing very rapidly, much like those of the natural sciences. Indeed, the phrase *"knowledge explosion"* is frequently used to characterize the intensity of the process. Therefore, the foregoing movement toward fundamentals and 'all-embracing principles' in engineering education is not without difficulties, because an increasing amount of *fundamentals* must be incorporated into the engineering curriculum within rather rigid time constraints.

Mathematics and Natural Sciences

The study of engineering fundamentals or engineering sciences is not possible without mastering the natural sciences. These in turn, especially physics, cannot be understood in depth without a solid understanding of mathematics, because, as Feynman (8) pointed out:

> "Mathematics is not just another language. Mathematics is a language plus reasoning; it is a language plus logic. Mathematics is a tool for reasoning."

However, the mastering of an increasing amount of natural sciences is necessary not only as a building block for understanding engineering fundamentals, but necessary for its own sake, because technology is increasingly rooted in the sciences. The fields of microelectronics, biotechnology, and materials are cases in point. In electronics, engineers dealing with building devices must have a firm grasp of solid state physics and materials, chemistry, physical chemistry and thermodynamics of surfaces. In chemical engineering perhaps the most important trend is the expansion of its scientific base to include disciplines not traditionally regarded as elements of chemical engineering. These must encompass physics, chemistry and biology, with far more emphasis on *microscopic* phenomena (6). Finally, mechanical and aeronautical engineers stretching the limits of application of materials must understand their physical and chemical nature far beyond the level that was deemed satisfactory by their predecessors. The fruitful, intimate, ongoing interaction between the natural sciences and technology brings us closer to the Baconian vision of a technology driven by systematic invention through science. Indeed, an increasing number of important technological innovations emerges from scientific research. How could engineers appreciate, adopt and apply the new discoveries to the artifacts they produce without sufficient understanding in the relevant natural sciences?

Design and Academic Respectability

However, the movement toward the sciences in engineering schools was also motivated at least partly by what Simon (9) called, the "desire of academic respectability." In terms of prevailing norms of the general culture of the university, academic respectability calls for subject matters "that are intellectually tough, analytic, formalizable and teachable." It is not surprising, therefore, that *engineering design or synthesis*, though the *central theme of the engineering activity,* perceived as "intellectually soft, intuitive, informal and cookbooky" was by and large purged from engineering curricula. Moreover, the desire of the academic community to deal with problems that have mathematical rigor, that are quantitative and intellectually challenging, frequently restricted them to *oversimplified engineering problems of limited relevance to real systems.* The real systems were far too complex, cluttered and empirical for analytic research.

These drawbacks of the science revolution in engineering education are discussed in the following sections. They both may be gradually eliminated by a new evolution-revolution triggered by computer technology. Yet, in spite of some drawbacks and some misguided motivations, the movement toward the natural sciences and the formulation and structuring of engineering sciences into teachable bodies of knowledge reformed engineering education, expanded its capability, made possible the sustaining of an ongoing technological revolution for decades, *and without doubt it is the only sensible firm guideline for the future. Therefore, it is expected that this movement will continue well into the 21st century.* The exact nature, content and optimal mix of the natural sciences and engineering sciences will vary from one engineering discipline to another.

Science and Technology

The main concern of engineering is to practice technology. Yet, as discussed in the foregoing section, engineering education has been permeated and preoccupied with the sciences – natural sciences and engineering sciences. Science and technology, however, are two different entities, though they relate to each other and interact in complex ways. The nature of this relationship is controversial and receives increasing attention from philosophers, historians, scientists and engineers (10).

'Science' is defined by the dictionary as "a branch of knowledge or study dealing with a body of facts or truths, systematically arranged and showing the operation of general laws." It is a clear definition. Unless the body of knowledge shows the operation of general law, it may be a branch of knowledge, but it is not science. In the words of Jules Henri Poincare, "science is built up with facts as a house is with stones, but a collection of facts is no more a science than a heap of stones is a house." In dealing with the natural sciences, the general laws are, of course, the laws of nature.

"Technology" is defined by most dictionaries, and perceived by society, as the "scientific study of industrial arts," or the "application of science to industry," or simply "applied science." These definitions are historically incorrect and greatly misleading, although, in certain "science-based" technologies they are coming true. To begin with, technology was practiced by man long before he invented the concept of science and the scientific method. How then could "technology" be "applied science"? "Where there is man there is technology," state correctly Bugliarello and Doner (10), who defined technology as *"the domain of man-made".* Indeed, as most practicing engineers would intuitively argue, technology is our accumulated knowledge of *"making all we know how to make"* (11). Technology, unlike science, could be successfully practiced without understanding the fundamental laws underlying its nature. There are many examples that can be quoted to support this contention. Metallurgy, for example, was actively and successfully practiced in the fifth and fourth millenia BC, thousands of years before the chemistry of metals was understood by man. The same argument holds, of course, for pottery and ceramics. Man built magnificent structures long before stress analysis was conceived. Rubber and plastics were processed into useful products before Herman Staudinger proposed his hypothesis on the structure of macromolecules, certainly before his hypothesis was finally accepted and converted into a Kuhn (12) type shared paradigm, and long before the complex rheological behavior of plastics and rubber was elucidated and mathematically formulated. Clearly, then, technology is *not* the theory of the practical arts, but the *practical arts themselves,* and science and technology differ in purpose and nature. Herbert Simon (9), in his lectures on the "Science of the Artificial," expounded the same idea in even broader terms. He suggested that in "science" one deals *"with things the way they are;" whereas, in technology (engineering) one deals "with things the way they ought to be,"* and the difference between the two is fundamental.

Science's main concern is *analysis*, that is, "the separating of an entity into its constituent elements." The objective of the analysis is to discover the laws of nature. The main concern of technology or engineering is *synthesis* or *design* that is, the combining of separate elements into a whole. In fact, *design is its fundamental characteristic, its central theme, and its claim to a separate identity.* Yet the engineering sciences have evolved through analysis, and this accumulated knowledge with further analysis is a powerful tool in the hands of engineers to probe into existing systems, machines, and processes to determine their reliability, discover their nature and optimize their operation. Engineering sciences reformed engineering practices, immensely increased their scope and improved their reliability. In addition, the tools of analysis have also had a catalytic effect on the process of *invention* and *innovation* (11), which are the driving forces of technological progress (13) and which are prime examples of engineering synthesis. Indeed, as Resnick (14) argues, analysis and synthesis in engineering are practically inseparable. "They interplay and interact, supplement and complement, like yin and yang." This interaction between analysis and synthesis, which is a reflection of the interaction between science and technology, leads in a spiraling way to progress in both science and technology.

Yet, engineering's main concern remains *design* – that is, the construction of artifacts that have a function and a purpose; and *design* being a non-analytic, non-formalizable and non-teachable subject was by and large purged from the engineering curricula. This purging was accelerated by the frequently shallow or non-existent design experience of the engineering faculty, the need to allocate more time to the quickly developing engineering sciences, natural sciences and mathematics within the time constraint of four years, and the failure of the engineering community to discover and formulate the *fundamentals of engineering synthesis* into a systematic, teachable body of knowledge. Consequently, engineering students are given, at best, a limited number of brief design experiences, or a one-semester final design project. They join industry with a flaw or missing design element in their background and they must learn design through apprenticeship on the job.

The answer to this problem cannot be the massive reintroduction of the design component into the engineering curricula in their present form. Neither is the answer in dogmatizing the existing situation, as suggested by Wei (15), and declaring that engineering education must be *shared* with industry, whereby academia's responsibility is to teach organized disciplines characterized by underlying general laws and principles (i.e. engineering science); whereas, industry's responsibility is to complement the formal engineering education with subject matters that are diffuse, characterized by experience and oral tradition, that are narrow in scope and studied through case histories (i.e. design and unstructured technologies). But it is believed that an important part of the answer lies in discovering the fundamental principles of engineering synthesis, along lines perhaps hinted at for the first time by Frantz Reuleuaux in his 1877 "Principes d'une Theorie Generale des Machines," and more clearly defined and formalized by Simon (9) in his "Science of the Artificial":

> "What I am arguing in this essay is not a departure from the fundamental but an inclusion in the curriculum of the fundamental in engineering along with the fundamental in natural science.*"

He then goes on to discuss several topics in the theory of design that are fundamental in nature; these include statistical decision theory, algorithms for choosing optimal alternatives (linear programming, control theory and dynamic programming) algorithms for choosing *satisfactory* alternatives, formal logic of design, heuristic search, allocation of resources and theory of structure and design organizations. Most of these are computer-related subjects. However, they relate to management systems and organizational components of design. Simon does not discuss in sufficient detail actual "hard-core" engineering design of machines and processes. However, one can expect with reasonable confidence that the computer technology which has been evolving since then may become the vehicle and catalyst to discover, formulate, and teach the underlying fundamentals of the science of design.

The future role of this computer technology in engineering education and engineering practices is discussed next.

Computer Technology – The New Revolution

Clearly, the engineering education in the 20th century has undergone an evolutionary-revolutionary process, as a result of the movement toward the natural sciences and the systematic creation of engineering sciences. However, as we approach the closing decade of this century, *a new*

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* Simon does not distinguish between natural sciences and engineering sciences.

revolution unfolds in engineering education and engineering practices, a revolution which might reach maturity in the next century, a revolution brought about by the new "computer technology", which leads to the wired university concept (16). The term "computer technology" includes computers of increasing capability and decreasing cost, interactive computer systems, exponentially increasing software capabilities, expert systems, artificial intelligence, computer graphics, vast, easily accessible data bases and global computer network communication. *The implications and consequences of this revolution in engineering education, engineering practices and technology in general will be not less significant than those brought about by the natural sciences in this century.*

To begin with, the new computer technology fires up and further boosts the science revolution in engineering because it provides a tool to discover engineering sciences to a greater depth, *just as it had done with science itself,* and permits for the first time to tackle quantitatively real engineering systems, machines and processes. This is being made gradually possible by easily accessible, powerful computing capability, advances in numerical methods, and quickly growing, rich data bases. This may change the current practices of the engineering faculty to deal with idealized systems, remote from reality, and irrelevant to industry, chosen because they are tractable mathematically. Simulation becomes a new tool of investigation, paralleling theory and experimentation, point out Balkovich et al. (17) in describing the M.I.T. Athena experience. So Charles Bababage's speculation in the 19th century that science will eventually come to a grinding halt because of lack of computing power is not coming true yet.

The fact that new computer technology permits tackling "real" engineering systems of increasing complexity, *implies, contrary to some common beliefs, that future engineers will have to master the engineering sciences as well as natural sciences to a much greater depth and expanded scope than hitherto required.* The future engineer who will routinely use sophisticated engineering packages, and certainly the one who will be developing the programs, will have to understand well the underlying physical principles upon which the program is based. Without such an understanding, he will either not be able to take advantage of the new tools or not be able to use them efficiently. Usually, the more advanced the computer program, the broader and deeper its physical, scientific and mathematical bases. There are many examples one can quote. The effective use of advanced finite element software for stress analysis, or for non-Newtonian flow, for example, requires an understanding of non-linear behavior in solids and liquids, respectively, as well as an understanding of the principles of the finite element method, variational analysis and the method of weighted residuals. A chemical engineer designing or analyzing a distillation column with computer software must understand multicomponent system behavior and thermodynamics far beyond the present standards. A polymer processing engineer using computer software for analysis and design of plastics and rubber processing machinery must study and understand the science of rheology, the behavior of time-dependent viscoelastic liquids and non-Newtonian fluid mechanics.

Clearly, then, the forthcoming computer technology will not only require the future engineer to *master a broad range of computer-related skills* to enable him to take full advantage of the new tool, but he will also have *to study engineering sciences to a greater depth.* Moreover, the subjects taught today in *mathematics will have to be reevaluated in light of computer technology.*

Machines freed mankind from the drudgery of manual labor, and computers will free the engineer from the drudgery of searching for data and computing, analysing and formulating the results. But beyond the massive improvement of the tools of analysis, the new computer technology might ultimately reform engineering synthesis. It should make it possible for the future engineer to devote much more time to *thinking, abstraction and generaliztion.* The future engineer should be able to concentrate not only on *how* to make a certain artifact, but to ponder *why* it is made that way. These are essential elements of *design*, which, together with the subject matters suggested by Simon (9), with new and perhaps controversial subjects like aesthetics in engineering, and with the unleashed power of computer technology in simulation, *should help discover the underlying fundamentals of design and help convert it from an "intellectually soft, intuitive, informal and cookbooky" subject to a "hard" science of the artificial,* and this will ultimately bring engineering its well deserved academic respectability.

Developing and teaching the fundamentals of design in engineering education, as well as sprinkling all subjects matters with open ended problems, as suggested by Denn (18), will hopefully help develop in future engineers the skills and a *desire for creativity and innovation,* because engineering is a creative profession. With a strong fundamental design element in the curriculum, the "on the job" training of a new graduate ought to be either shortened or made more efficient. It is unlikely that it will be altogether eliminated, because the ongoing technological revolution also generates vast amounts of new, as yet unformalized design know-how.

Denis Gabor (19), the inventor of holography, maintains that:

> "The conclusion appears unavoidable that the computer will produce an 'aristocratic revolution' in the engineering profession. Only creative minds will be needed and competent programmers. Yet the engineering universities are turning out more and more graduates, the majority of whom cannot become anything other than routine engineers."

It is hard to agree completely with Gabor, because industry also needs *routine* engineers. But his idea about the 'aristocratic revolution' can perhaps be formulated somewhat differently. It can be claimed that a possible byproduct of the computer revolution will be a *bifurcation of engineering education* into "aristocratic engineers" with very strong scientific bases, fully immersed in computer technology, working on real problems and creating the engineering computer software and new design concepts, and the "routine engineers" involved in important but more common engineering work using, but not developing, computer software.

Clearly, a four-year education will not be sufficient for the "aristocratic engineer," but it may be sufficient for the "routine engineer." A trend in this direction already seems to emerge in the United States and elsewhere, with the Engineering Technology degree. Graduates with this degree focus on the mastery of engineering practices, surveying, drafting, etc. They function in technical support roles in similar fashion to nurses and medical technicians. Yet the nature of the "routine engineers'" education is an open question. Should they be trained in practical matters, like engineering technology graduates, or should they also enjoy a broad fundamental education? The answer is surely the latter.

Technology and Society – Humanities Revisited

Technology has emerged as the dominant factor in determining the future nature of society. "To say that a technological revolution is underway is almost to utter an understatement," says Ramo (20). Technological and science expanded the world population and created an interdependence that only continuing technological progress can sustain. A massive return to the pre-technological society, as preached by anti-technological fundamentalist movements, is possible only through a holocaust. Mankind's very survival depends on technology and on man's control of this technology. The most ordinary functions of living are now served by complex technology. So both the hopes and fears of many are directed toward the protagonists of the technological revolution – the engineers and scientists. They, in turn, argues Pollara (21), only now have started to realize that politics, economics, social arrangement, and arts and letters can no longer be usefully conceived as isolated and distinct from the technology on which our society lives and grows, and he correctly claims that "the revolution of our times is not separately social *and* technological, it is simply a social revolution of inconceivable potential resulting from the extraordinary success of technology in making available for human purposes an energy so great that it is transforming not only the fundamental organization of society but necessarily also technology itself." When technology was a minor force in society humanists could disregard it and keep it outside the mainstream of culture, and engineers could comfortably adopt a "club-like" status. But, under present and future conditions, the engineer can no longer remain a detached specialist, he must accept full human responsibility. To discharge this duty wisely, his education must prepare him for the task.

Much controversy, however, exists in the humanists' view of technology, reflecting an ambivalent view of society itself. Both Herbert Spencer and Karl Marx recognized technology as a central element in the evolution of society, though they reached different conclusions. Some viewed technology as "neutral" Technology "opens doors but it does not compel one to enter," claimed the historian Lynn White Jr., who apparently gave more credit to human wisdom and determination than man seems to possess. Jacques Ellul believed that 'la technique' controls our lives (22), as did Lewis Mumford (23). Kranzberg (13), on the other hand, argued that "technology is neither good nor bad – *nor is it neutral,*" by which he meant that 'technology interacts with society in ways which do not seem necessarily inherent in technology itself." Humanists must therefore study technology in order to understand social change, and engineers must study humanities in order to appreciate the complex interaction between society and the technology they help create.

But beyond the moral and ethical need to study humanities, there are more pragmatic reasons to do the same. The Committee on Education and Utilization of Engineers (7) argued that exposure to course work in the humanities, arts and social sciences, over an extended period of time (i.e.

beyond freshman and sophomore years), offers many advantages in molding the contemporary engineer. It improves his judgment, values, and communication skills, and in a global marketplace, gives him a greater exposure to the world of ideas and equips him to better deal with the inherently complex situations. Therefore, the engineer becomes more competitive. Moreover, such a background also helps the engineer to better cope with the changing social, economical and political conditions that will also affect technology and its development.

The Technion's, as well as many other universities' requirements in humanities do not answer the needs of future engineers operating in a global marketplace and having an increasingly large input on social decisions. Instead of a random collection of courses in history, arts, and philosophy, there is a need for a *well-designed program of carefully integrated courses in the history of human civilization in social sciences, in philosophy and the arts*. The Septennial Committee (6) clearly defines the present situation and expresses the need for such a course:

> "The frequently expressed, but usually undefined, need for more humanities is not as compelling as a well-defined, broad approach to history, literature and philosophical thought. It is important to understand the origins of one's own culture as well as that of others. Innovative approaches are possible. Existing courses in literature and world history could be reorganized to complement each other so that the literature of each historical period is stressed. History should include political, technological, social and economic aspects. Special well integrated courses designed to meet these needs should be of much greater benefit than the usual distribution requirements that often results in random selection from a cafeteria of course."

The only possible additions to this crisp statement would be to include into such an integrated course the principles of aesthetics, because of its relevance to engineering design, and follow it up with a special course on the philosophy of science and technology.

Communications Skills, the English Language and Managerial Skills

Beyond a solid grasp of natural sciences, engineering sciences and mathematics, of computer-oriented subjects and skills, some training in humanities and hopefully an understanding of design and some competence in the fields of modern technology, future engineers need a number of additional skills to make them capable professionals. These include written and verbal communication skills, fluency in the English language, a basic understanding of economics and some grasp of management techniques, tools and principles.

The widespread opinion within industry in the United States is that the competence of recently graduated engineers in analytical skills and engineering sciences is good, but that they are missing most of these additional skills (5). The lack of education in the management of engineering functions (as distinct from the MBA-style management) was specifically stressed, perhaps in view of the fact that about one-third of engineers in the United States are in management by work activity classification (24). *Yet, in view of the increasingly crowded curriculum to be discussed in the following chapter, this committee recomends that management-related subjects, as well as economics, should be postponed to graduate and continuing education studies.* The fact that most engineers are promoted to engineering management levels only several years after their graduation lends support to this recommendation.

However, there is a unanimous agreement on the need to stress and improve communication skills.

One of the key recommendations of the Committee on the Education and Utilization of the Engineer (5) on future engineering education deals with the foregoing broad range of nontechnical skills:

> "In addition (to a broad engineering education with strong grounding in the fundamentals of science) the curriculum must be expanded to include a greater exposure to a variety of nontechnical subjects (humanities, economics and sociology) as well as work-oriented skills and knowledge. Education in these areas is needed *to improve the communication skills of engineers* as well as their ability to understand and adopt the changing conditions and affect technological development."

The Septennial Committee (6) also stresses the need for improved communication skills, and recommends requiring oral presentations in at least one course each year, and at least one course with substantial writing requirements and several literature surveys. In addition, it recommends more stringent entrance requirements regarding the verbal S.A.T. (Scholastic Aptitude Test).

The Technion graduate also severely lacks oral and written communication skills, as do most other engineering graduates in Israel. The source of the problem, however, is far deeper than the structure and content of the engineering curriculum.

Most elementary and high schools put a low priority on improving these skills, in particular verbal communication. Clearly, even if the Technion did its utmost to improve the standards, which it does not, it would be a continuous uphill battle. Nevertheless, it is imperative that the *Technion place major emphasis on improving oral and written communication skills.*

In view of the severity of the problem, the committee recommends adopting the foregoing recommendations of the Septennial Committee, and *in addition, it recommends considering the introduction of a special course in written, oral, and technical communication.*

All that has been said on communication skills in Hebrew holds of course for the English language as well. In fact, the fluency of most students in the English language is so poor that they find great difficulty in using their English textbooks. This, of course, has a profound negative impact on teaching methods and learning habits. Since virtually all textbooks are in English, how can one expect self study habits when students have reading and comprehension difficulties? Rather than reading textbooks and reference materials the students rely entirely on class presentation, which, of course, cannot be and should not be an alternative to textbooks and reference books.

But fluency in the English language is important not only to the engineering *student* but also to the *graduate* engineer. Fluency in English must be one of the future engineer's attributes. Israel's future in the 21st century will depend on her technological edge in a global marketplace and global technology dominated by the English language. This implies day-to-day exposure, contacts, discussions, negotiations, exchange of information and social meetings with the worldwide community of engineers, scientists, and managers, to be conducted in the English language. Fluency in English, therefore, is a necessary tool to sharpen the competitive edge of Israeli technology. Present English teaching practices and requirements at the Technion are not sufficient. Concentration on teaching *"technical English"* should be reconsidered. Students should learn the *English language;* technical expression can be picked up in the course of studies. English studies should be extended beyond freshman year.

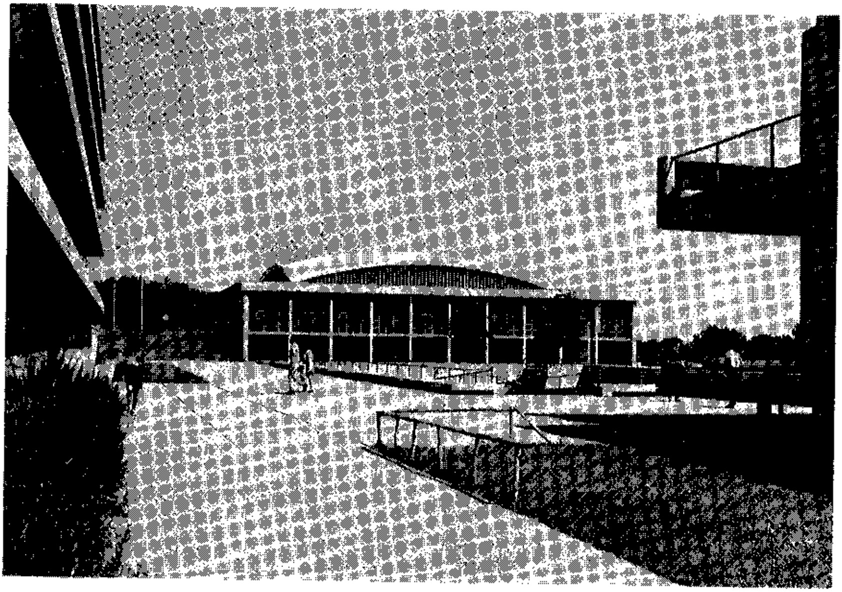
Innovative approaches are badly needed to trigger interest and motivation in students. *Teaching one technical subject a year in English and intensive refresher courses in the summer should certainly be considered.*

Interdisciplinary Exposure and Multidisciplinary Studies

Engineers study and operate within their disciplines. In fact, a recent survey shows that about ninety percent of engineers in the United States are employed in engineering or scientific jobs and work in their degree fields (25). This in spite of the fact that the mutually shared base among engineering disciplines increases, and much can be said in theory in favor of general engineering as a single all encompassing engineering discipline (21). Yet each discipline has its unique flavor, its jargon, its professional society, its own closely knit international membership. Belonging to a specialized professional peer group not only satisfies some apparent psychological needs, but also serves very pragmatic goals. The amazing resilience of traditional engineering disciplines bears evidence to these needs.

But while engineers operate within their own discipline, new technologies are causing a blurring of the boundaries between engineering functions (e.g., design, manufacturing, marketing and management) (6), and they are multidisciplinary in nature (e.g. biotechnology, robotics, oceanography, and space exploration). In fact, virtually all large engineering projects are multidisciplinary in nature. Successful operation within the new technologies and interdisciplinary projects requires some exposure of students in one discipline to other disciplines. Therefore, it is desirable for engineering students to participate in at least one interdisciplinary project during their studies.

A thorough preparation targeted to a new technology may require pursuing joint programs of two disciplines. The Technion has encouraged this positive trend and joint double-degree programs exist between physics and electrical engineers, chemistry and chemical engineering, biology and chemical engineering, computer sciences and industrial engineering, among others. Similarly, masters degree programs cutting across disciplines, and clustered around some interdisciplinary subject, are to be encouraged. This is discussed in more detail in Chapter 2.



Churchill Auditorium, Technion City, Haifa
Photo: Keren-Or, Haifa

2. CURRICULUM COMPONENTS

Overview of Curriculum Requirements

The Technion engineering curriculum, like most engineering curricula in the western world, has become increasingly science based, and it stressed fundamental, broad principles. Therefore, the curricular changes dictated by future trends, as elaborated in Chapter 1, are more evolutionary than revolutionary in nature. But these curricular changes call for *many additions* of subjects and skills, and in view of the already bulging four-year curriculum, their incorporation will call for *fundamental restructuring* of engineering curricula at the Technion, and for certain important changes of the Senate rules and regulations.

The following sections outline the changes this committee suggests for incorporation into the engineering curricula, to answer future needs:

1. Mathematics

There is a need for broadening the mathematical base in engineering education, emphasizing subjects such as numerical methods, approximate methods, finite mathematics, non-linear analysis, asymptotic methods and mathematical principles of graphics. This is a need brought about by advances in the engineering sciences and computer technology. The committee feels that these subjects should be part and parcel of future engineering education even at the expense of the present more classical mathematical subjects. The subject matter taught today must be carefully scrutinized to eliminate less relevant subjects and mathematical rigor where it is not absolutely necessary. Finally, the use of computer software in symbolic algebra and calculus* for both teaching of mathematics and for routine engineering analysis in engineering sciences that enable students to deal with "tougher" problems should be encouraged.

2. Natural Sciences

There is a fast growing body of knowledge in the natural sciences that engineering students must learn. Future technologies will be based on a broader spectrum of scientific subjects and disciplines. In teaching physics and chemistry, emphasis should be placed on this broadening scope of the scientific base, rather than on the standard subjects, some of which are taught in engineering sciences in greater depth and sophistication. Biology and material science will both play increasingly significant roles in future technologies. Both require a solid understanding of chemistry and solid state physics beyond the levels reached presently in most engineering departments.

Each discipline, of course, must define its own needs in natural sciences. The common denominator of these requirements, together with those aspects of natural sciences that are an indispensable part of the general education of a modern engineer, should form the institute requirements.

3. Engineering Sciences

The structuring and formulation of engineering sciences into a "teachable body of knowledge" is the core of the revolution in engineering education in this century. As pointed out in Chapter 1, it is an ongoing process of immense impact. Most of the research effort of the engineering faculty is centered on these subjects. The vast amount of structured, formulated and teachable knowledge that is accumulating poses the painful dilemma of *selecting* and *discarding* subject matter for the engineering curricula. Due to severe time constraints, the danger, of course, is that less and less of the available knowledge can be taught to engineering students. The need for greater depth and a broader scope in engineering sciences, is demonstrated not only by the fact that the knowledge exists, but as a result of computer technology the use of the new knowledge quickly becomes common practice and engineers must therefore master it. Consequently, the portion of engineering sciences in the curriculum must be increased.

In teaching the subjects of natural sciences and engineering sciences, the

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* e.g. MACSYMA (Symbolics Inc.), muMATH (The Soft Warehouse), REDUCE 2 (University of Utah), and SCRATCHPAD (IBM).

need for advanced laboratory experience cannot be overemphasized. This experience not only converts abstract, vague knowledge into tangible reality, but familiarity with advanced instrumentation provides the students with both application of scientific principles to practical use, as well as outstanding examples of engineering design.

4. Design

There is an urgent need to strengthen in the curriculum the design element by adding courses wherever possible on the fundamentals of design, and by incorporating open ended problems in most engineering science subjects. Concurrently, the curriculum should be purged of archaic empirical design approaches. The area of design will probably undergo fundamental changes in the next decades and designers of engineering curricula should take note of these changes.

5. Computer Technology

A substantial increase of computer related subjects and skills in the curriculum is needed. These include fluency in computer languages, computer graphics, data base management and manipulation, familiarity with one standard operating system, text editing, construction and critical evaluation of large software packages, data acquisition, some understanding of hardware elements, and computer-controlled processes. The student should learn to apply these skills to solving engineering problems.

6. Humanities and Social Sciences

The present system of offering students a wide selection of courses from which they are free to choose should be abolished and replaced by a new program which will make humanities and social science courses an institutional requirement, and which will offer the student a very limited choice of coherent and well-integrated programs. Examples of such programs are courses in civilization which integrates history, literature, art, science, technology, sociology, philosophy and aesthetics, courses in the history and philosophy of science and technology; logic, and courses in economics and social sciences.

7. The English Language

The teaching of technical English should be replaced by the teaching of the English language. Institute requirements should be substantially increased. Teaching of one course a year in English should be considered. Intensive pre-freshman and summer courses in English should be considered.

8. Management Skills

Management related subjects should be postponed to graduate or continuing education studies.

9. Communication

Greater emphasis should be placed on improving the written and oral communication skills of students. The introduction of a one-semester course in written and verbal communication, as an institute requirement, should be carefully examined. It is recommended that at least one course each year stress oral presentation, and at least one course each year have substantial writing requirements and several literature surveys.

10. Interdisciplinary Exposure

Efforts should be made to incorporate into the curriculum elements of interdisciplinary work. One way to approach this problem is by forming small research or project teams from different disciplines carrying out a research or engineering project. These can best be accomplished within the honors programs (See Chapter 3).

There is no doubt that within the present set of rules and regulations, which provide students with substantial freedom of choice, and within the four-year time constraint, it will be very difficult to incorporate the foregoing recommended changes into the engineering curricula at the Technion. Moreover, the need to reduce the overall load on the Technion student, discussed below, makes the task even harder. Yet, the changes ought to be made and a solution must be found. The educational alternatives for accomplishing this task are discussed below, following a brief discussion on learning patterns of students and on high school education. The former sets the boundaries for what can be accomplished in engineering education, while the latter sets the initial conditions for this educational process.

Learning and Teaching Patterns and the Overloaded Student

The Technion student is overloaded. Few will argue with this statement. The students agree with it, most professors agree with it, and so do virtually all the departmental evaluation committees. An overworked student will spend on each subject the minimum effort needed to get by. He or she will not spend extra time on subjects of interest. Under the constant stress of unfinished homework, examinations and laboratory reports, the norm becomes learning with little in depth understanding, careful and selective preparation for examinations molded in the image of the professor and his classroom presentations, and learning without the psychological reward that is best termed "the joy of understanding." An overworked student, even if he is a very good one, will shy away from any extra work needed for independent study and honors courses. Therefore, excellence in education can hardly be achieved, and educational elitism cannot be pursued.

There are a number of reasons why the student at the Technion is overloaded. To begin with, the Technion overall credit requirements are high.* They exceed those of many comparable engineering schools in the United States, and while they are similar to some of the European engineering programs, these latter programs are usually 5 to 6 year long. Not only is the overall credit requirement high, but the amount of time learning 'hard' engineering science courses is higher than in comparable engineering curricula in the United States. Moreover, the English language problem prevents the student from efficient use of textbooks, and consequently frontal teaching and recitation hours are appropriately lengthened, placing heavier demands on students' time. Another important reason for the heavy load placed on students is associated with curriculum structure. The Senate requirements for allocating a total of about 40 credits to free electives (10 credits) and engineering electives (30 credits) forces departments to 'squeeze' all engineering science and design requirements into about one third of the total credits.

There are, however, among the faculty and graduates those who share the notion that simply reducing the load on students will not change their learning and work habits, but merely free some time for non-academic activities, and the end result will be a deterioration of standards. This notion has neither been proven nor disproven. Yet, perhaps the answer lies not in simply reducing the load, but *shifting emphasis by reducing the formal load and at the same time increasing depth through self-study and student-faculty contacts.* The idea is not to let students study less, but to instill in them the

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* The Technion specifies 155 to 165 semester credits for a B.Sc. degree in Engineering. Most departments cluster around the upper limit.

feeling that they can afford the time to probe deeper into the subjects, and the *willingness* to do so. Present Technion practices force students to become *technicians* of homework problems, examinations, and laboratories. The word "technician" is used in the sense that the students learn the superficial skills and tricks to solve homework problems and pass examinations with "minimum thinking." Teachers and students 'collude' in this 'anti-intellectual' conspiracy. In different ways, it is a convenient arrangement for both. Yet the foregoing objectives of the future engineering education cannot be achieved without a sharp departure from present teaching practices and learning habits.

The British Working Group (4), for example, specified "adaptability" as the second most important characteristic to "understanding of fundamentals" of the future engineer. "Adaptability", according to the Working Group, implies:

> "the ability to apply relevant science to systems and situations which may have not existed during the engineer's student days; therefore, not only must the science be understood, but a *willingness* to observe and learn about new systems, and the *ability* to describe them in terms which lead to an understanding of their behavior, are also needed."

"Adaptability", in this sense, depends not only on the *subject* matter taught, but also on the *manner* in which it is taught. It is intimately related to the teaching methods of professors and the learning habits of students. Deeply rooted self study habits, free, frequent and open class discussions, small seminars, special projects, rather than "frontal teaching," are the essential components of a teaching environment fostering "adaptability."

Thus, prerequisites to a departure from present teaching and learning patterns are, among other things, a reduction in the formal work load on students, a mastering of English, a change in examinational policies, a reasonable student-faculty ratio, the introduction of honors programs, and, finally, it requires the faculty to perceive students as young adults searching for a solid education, rather than as high school kids trying to get by, and it requires students to act as adults.

High School and Pre-University Studies

Changes in education cannot, of course, be considered in depth without paying attention to what precedes it and what follows it.

High schools, as pointed out above, set the initial conditions and, by and large, do not prepare students sufficiently for science and engineering studies. Their preparation in mathematics, physics and chemistry is poor, as is their fluency in English, their communication skills and their exposure to a universal cultural experience. Although 36% of high school graduates matriculate in science and biology (as contrasted with humanistic studies) and 32% take extended credits in mathematics, only 6% take extended credits in both mathematics and physics, and only 1.4% take extended credits in mathematics, physics and chemistry.* Moreover, about half of the high school population graduates from technological high schools with an even less thorough preparation in sciences and mathematics.

The majority of Technion freshmen (63%) are army veterans. The median age of the Israeli male freshman is 24, and that of the female freshman is 21. Not only does the typical Technion freshman, therefore, spend long years in the army, but before starting his studies he needs refresher courses in mathematics, the sciences and English. This is being provided by the University Preparatory Units associated with most universities. About 60% of all Technion freshmen go through a refresher course of six months to one year. Although these preparatory units perform a very useful function, that also has an important social purpose (about half of the students in these courses are underprivileged youths), the utility of intensive study oriented toward passing university entrance examinations is questionable.

Indeed, the committee has considered the option of opening the Technion freshman year to most students, eliminating the need for a refresher course, and providing appropriate courses as an integral part of their study, and selecting promising students at the end of the first year. Thus the "refreshing" would be done in the university with, it is hoped, a more effective utilization of the student's time, a more streamlined educational program, and a more reliable selection process for the better students. However, the idea was discarded for a number of reasons. To begin with, there were no assurances that the Technion proper would do much

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* Based on the Israel Central Bureau of Statistics in 1980.

better than the preparatory program. Moreover, the present selective and careful admission practices help the Technion's image and drive for excellence. Finally, adding another year or even one semester for all students would be wasteful and discouraging to many good students.

The consequences of inadequate preparation of high school graduates limits the attainable standards in freshman year sciences and mathematics. Subject matters that should be taught in high school are taught at the universities. The committee feels that this trend should be immediately slowed and, ultimately *reversed.* The growing data base of knowledge and the time constraint imposed on undergraduate education make it necessary that more and more freshmen subjects in science and mathematics ultimately be taught at the high schools.

Yet, in spite of the inadequate preparation of high school graduates and the possible detrimental effect of long army service on university education, the Technion and engineering schools in general are fortunate to receive the better qualified and more intelligent high school students. The Technion should continue to put major efforts in trying to attract the very best of the high school crop. This also implies a *vigorous effort to increase the female population of the Technion* which stands today at 16%. Thus, a large untapped human resource is lost to engineering, which has ceased to be a male oriented occupation, and to the Technion.

The need for additional subjects and skills that the future engineer must be taught, and the need for some reduction in work loads cannot be jointly met unless some educational constraints are relaxed. Among these could be radical changes such as extension of the B.Sc. degree to a five year program.

The idea to extend the engineering education beyond four years in response to the exploding growth of knowledge is not new. The Goals Committee (2) lists the following options:

1. A four-year program in engineering leading to a bachelor's degree, followed by graduate programs leading to a master's degree.
2. A five-year program in engineering leading to a bacherlor's degree that may or may not be followed by graduate work.
3. A five-or-more-year program in engineering leading to master's degree in engineering or in a specialized branch of engineering. This program as well as the previous one is intended primarily for those who intend to practice engineering at a professional level.
4. A four-year program leading to a bachelor's degree, not necessarily in engineering, to be followed by an engineering program, probably of two

or more years duration, leading to a master's degree or a higher degree in engineering.

5. A four year program leading to a bachelor's degree in engineering not necessarily followed by graduate work (i.e. the present standard situation in the United States as well as in Israel).

There are many engineers who feel that the last option is still satisfactory for many engineering needs. In fact, 93% of all engineers in Israel have only a four year education leading to a bachelor's degree, though the trend is toward a larger proportion of higher degrees in engineering. The Goals Committee in the United States did not identify any of the above as the best route, but recommended diversity and that each institution select the best route for its own needs.

In Europe, five-year programs leading to what is called "diplome engineer" is standard procedure.

The committee has considered the option of extending engineering education beyond the present four-year program, and it has rejected this option for two main reasons: first, it agrees with the apparently accepte notion that one-half to two-thirds of all engineers do not need more than four years of engineering education. Many of these engineers will be doing routine engineering work. Second, it is unreasonable to keep students who start their education at the very late age of 24, many of whom are married and have families, for five years in school before awarding them a degree. Rather, the committee strongly recommends *far greater emphasis on graduate and continuing education. Graduate education is for promoting excellence, for engineering specialization, and for reaching entry level standards in certain engineering fields; whereas, continuing education is for keeping abreast of developments, and retaining adaptability to new conditions, as discussed below.*

If the extension of engineering education is rejected and the four-year time constraint on the bachelor's degree is retained, then the reduction in student work load and the recommended changes in the educational process must be accomplished by a major revision of the curriculum. This includes the following major elements:

a. Extensive disciplinary specialization must be postponed to the graduate level, as also recommended by the Committee on the Education and Utilization of the Engineer (7).
b. Electives, both free and departmental ones must be substantially reduced, and replaced by coherent study programs clustered around

major themes. In each program emphasis should be placed on an in-depth study of the engineering sciences.

c. Honors programs for above average and highly motivated students should be introduced. (This is discussed in detail in the next chapter.)

d. Teaching methods and learning habits ought to be renovated. Individual self-study from textbooks should be enforced upon the students. (A prerequisite of this is, of course, fluency in the English language.) Ways to accomplish this include *separating the subject matter taught in class from the subject matter required for the examinations,* extensive reading assignments and submission of reviews. "Open ended problems" should be incorporated in all homework assignments. Seminars for honor students should be associated with most engineering science courses. Non-creative, routine problems should be eliminated from homework and even from examinations. Classroom presentations should not be a recitation of the textbook, but should concentrate on discussing the subject, illuminating interesting concepts, making parallels and connections to other subjects and to real technology, and instilling in the students the underlying logic, feel and texture of the subject matter. Formal problem solving classes should be replaced by question and answer sessions.

The committee feels that with these changes a broad engineering education, firmly grounded in fundamentals, in line with the recommendations summarized in the overview section can be accomplished *with a total of 144 credits; that is, 18 credits or an average of no more than 6 subjects per semester, according to the following guidelines:*

Mathematics and natural sciences	30-35%
Engineering sciences	35-40%
Design and computer technology	15-20%
Humanities, social sciences, communication and English	10%

Graduate Studies for Entry Level to Advanced Engineering

An inseparable part of the above revisions of engineering education is the introduction of honors programs and the *vigorous encouragement* of about one-third of the top students to continue their studies for a master's degree. Credits for the honors courses would also be accepted for the master's degree. The master's program of the Technion should offer a host of cohesive departmental and interdepartmental programs clustered around specific subjects. These programs ought to meet any of the following needs: to bring the young engineering graduate to the leading edge of specific technologies, to introduce strong interdisciplinary elements, to bring the engineer to entry level in certain engineering activities and to encourage continuing education. Examples of such programs are:

Solid state and semiconductors
Electron optics, lasers, and fiber optics
Computer graphics and design
Computer aided design
Biotechnology
Robotics and artificial intelligence
Policy analysis
Polymer processing
Numerical analysis in engineering
Space engineering and technology
Oceanographic engineering
Environmental engineering
Health related technologies
Reliability and quality control
Water resource systems and technology

Because many of the courses are interdisciplinary in nature, as is modern technology, the responsibility of the Graduate School at the Technion must be expanded from *administrative* responsibility to *academic* responsibility in creating and coordinating the interdisciplinary master's programs, and in accepting students and following their progress. The master's degree in these programs will be given not by engineering departments, but by the Technion.

These programs will, of course, not replace but supplement existing research-oriented programs.

Continuing Education

A young doctoral graduate takes it for granted that continuing studies will be an integral part of his professional life. This attitude, however, is *not* generally shared by the young B.Sc. or even M.Sc. graduate. Perhaps this is because the former has experienced intensive research at first hand, and probably will continue to do research and development in his professional life. But when technological and scientific progress continue to be exponential, it is essential *for all engineers to continue to study, formally and informally* throughout their professional lives. Clearly, undergraduate education at best can only provide a sound basis on which to build for a lifetime.

The desire to continue to study must be instilled into the student from the first day of the freshman year. The method by which this can be done is by showing students the frontiers of knowledge in each field, by stressing what we *don't* know as much as what we do know in that particular field, and by providing students with a historical perspective of the subject. Once students realize that virtually all engineering disciplines are "open" and not "closed" fields, they should be more likely to accept new knowledge. Moreover, once the concept of continuing study and improvement is internalized, the process of "unlearning" the old, the obsolete knowhow and practices, becomes much easier. This is important because often, "unlearning the old" is more difficult than "learning the new."

Yet, continuing education is needed not only to acquire "critical masses" of knowledge in the familiar engineering disciplines, which makes self-study possible, and which is by and large done in formal graduate classes, but also to acquire specific skills required for a defined job, to familiarize the student with other disciplines in multi-disciplinary projects, and to acquire management skills and techniques at the appropriate time in a professional career.

Engineers must therefore be encouraged to spend time on continuing education, and employers must permit and encourage such continuing study. *A drive for formal, state-enacted law requiring additional studies for engineers, in particular for professional engineers, should be carefully examined.*

So far, universitites have not accepted responsibility for continuing education. There are many reasons for this, which are beyond the scope of this report. Yet, in view of the central role of the Technion in engineering education in Israel, the committee recommends that the *Technion accept the challenge of becoming a national and international center for continuing education in all technology related subjects.*

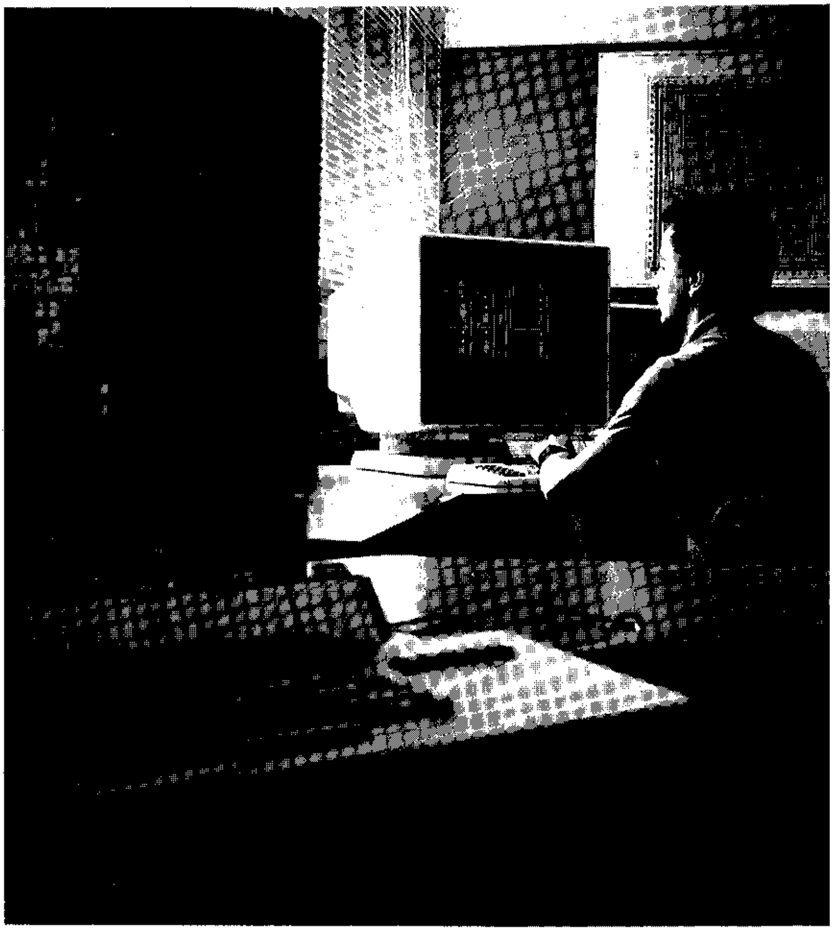

Photo: Shlomo Shoham – Photography

3.

DRIVE FOR EXCELLENCE

Quality and Quantity

There is nothing unique about a drive for excellence. All universities strive for it. No university has yet set mediocrity as its cherished goal. Yet precious few can claim that they have achieved excellence. Excellence or superior quality is very hard to define but is very easy to recognize. Quality in universities is a reflection of its faculty. "In a very real sense the faculty *is* the university – its most productive element, its source of distinction," Kerr states correctly (26). Universities produce graduates and research. Indeed, teaching and research are inseparable, for teaching, in particular graduate teaching, must be up to date, and research involves keeping abreast of work of other people and institutions. Moreover, only through research is it possible to peel off the many outer layers of technological subjects and reach their inner core, their essence, their fundamental principles, and only by grasping this core is it possible to teach a subject well. A measure of a university's excellence is therefore in the quality of its research and the quality of its graduates, in particular master's and doctoral graduates. Outstanding departments may nevertheless produce mediocre bachelor's graduates, but not vice versa. A quality university with selective admission and a small undergraduate school will produce not only good research and top doctoral graduates, but also quality bachelor's graduates. However, a quality university with a large undergraduate student body wishing to produce excellent bachelor's graduates faces some dilemmas. The Technion is in the latter category. Not all graduates can be excellent. Moreover, industry needs, in addition to excellent graduates, also good solid graduates. How can excellence be produced side by side with the ordinary, without making the ordinary bad? This is the first dilemma. The second one involves the painful decision of resource allocation. In a democratic society this is also a moral dilemma. How should resources be allocated among students with high aptitude, in order to take advantage of their potential for outstanding contribution, and among those with lower aptitude, in order to make up for handicaps in their background? Blau (27) claims that this is the "ultimate" dilemma of higher education. He argues that the academic value system creates predispositions to concentrateon those students whose early promise maximizes the chance that they will make original contributions to knowledge, yet, he continues, the populist and anti-intellectual themes in American culture produce opposite tendencies. Blau's findings are valid also in Israel, though the source of anti-elitism is not populism but a historically rooted notion that egalitarianism and elitism are contradictory (28). However, the question really is which choice serves society better? Israel's economic and physical survival in the 21st century depends to a large extent on its competitiveness in high technology. Does its high technological base depend most on adequate training of large masses of engineers, or on the great contributions only the best minds can make? Surely it depends on both. The question concerns the proportions of the two. The Technion so far has neglected the "elite," *This committee argues that future needs and the Technion's true interests jointly dictate a change in philosophy and perception, whereby emphasis on quality should be increased and that on quantity somewhat reduced.* This is discussed next.

The Global Technology, Market, and Competition

From the mid-1960's, a global market and a global technology started to evolve. Beginning with the General Agreement of Tariffs and Trade in 1947, industrialized nations gradually reduced their tariff levels. Developing nations gained easy access to international capital through the World Bank, and technology began moving fluidly across the globe. It can be purchased easily. Technical training can also be purchased and technical supervision is easily accessible. Global channels for sales and marketing opened up. Changes have been accelerated by transportation and communication. The world is fast becoming a single marketplace (29).

Thus, a major structural change in world economy evolves. High volume, standardized products with modern, automated machinery and quality control move into developing nations. There is a process of fragmentation and specialization in manufacturing goods at hand. Parts of the same product are manufactured by highly especialized plants in different parts of the world. Consequently, industrialized countries move into product lines that require a highly skilled labor force – precision products, custom-made products and technology driven products. In technology-driven products, by the time high volume is reached, the product has already become outdated. These categories require all business functions (research, design, engineering, purchasing, manufacturing, distribution, marketing and sales) to be integrated into a single system that can respond quickly to new opportunities ("flexible system") (29). Japan is outstanding in switching from capital-intensive to flexible system production. The distinction between goods and services becomes blurred. The economic future of the industrialized countries lies in the technically advanced, skill-intensive industries, commonly referred to as "high technology industries."

Israel, with its very limited natural resources, with its small and relatively expensive labor force, but with a solid base in sciences and engineering, has no choice but to seek its economic future in the high-technology industries. Fortunately this is fully compatible with its basic defence needs. In fact, the large defence industry Israel must maintain for securing its physical survival is the driving force toward high technology. The movement of Israeli industry toward high technology is not only inevitable, it is also timely, because the historical stage of creating the standard industrial base of the country has been completed. Expansion is only possible through export, and the best prospect for export lies in high technology products. The movement is urgent because the massive support Israel receives from the United States will not and should not go on indefinitely, and if, by the time it dries up, Israeli high technology industry will not be on a solid footing, consequences may be very serious.

The movement of Israeli industry toward science intensive advanced technology has profound consequences on engineering education and ought to alter Technion policies as well. From the point of view of engineering education, the first corollary of the foregoing global changes and the gradual restructuring of Israeli industry is that *future engineers will have to compete with the best engineering minds in the world.* The second corollary is that they will have to be *extremely adaptable* to quickly shifting technologies and products. The obvious consequence of the former corollary is that the Technion, and Israeli universities in general, will have to develop programs fostering an elite and cultivating the future technological leadership through special programs, whereas the natural conseqeunce of the second corollary is adopting the changes in engineering education as proposed in this report.

The Technion's Role in Engineering Education

In this scientific era, universities have become a prime instrument of national purpose, and they serve as the focal point of national growth (26). This modern view of universities is fully compatible with the Technion's objectives as stated in its charter:

> "To serve the State of Israel and its economy by counsel and research, and by other appropriate means, and to serve the people of Israel by the provision of courses of instruction and lectures, the publication of books and similar activities in the areas specified above."

these being pure and applied science, engineering, architecture, technology and related activities including humanities, social sciences and education. Clearly, then, if Israel is at the beginning of the 21st century technological era, the Technion as the country's major technological institute, must play a central role in shaping the country's technological future. For several decades now the Technion has perceived its central role as the supplier of the masses of engineers the country needs for its development. The Technion has invested much effort in providing engineers of the best quality it could produce. These efforts were successful. Some 75 percent of the engineering force in Israel are Technion graduates, and the Technion has grown with the country in size, diversity and stature. The deeply-ingrained philosophy of growth, of being a mass producer of engineers, the main supplier of engineering manpower to Israeli industry, was timely and complimentary to young Israel's needs of building up a grass roots civilian and military industry necessary for its survival. Department after department was built and staffed in anticipation of forthcoming needs. But, as noted, a new stage in Israel's development has been reached, whereby Israel's only hope for economic growth is the manufacturing of goods and services which can be exported. These are by and large "high technology" products and services, and they place Israel squarely in the global market, facing global competition with all the consequences discussed in the foregoing section. If the Technion is to fulfill its obligations to society, it must revise its philosophy and chart a new course in engineering education which is more compatible to future needs. The new philosophy ought to stress educating *not* only masses of engineers, meeting future needs as discussed in this report, but *educating also, with equal or even greater vigor, the engineering* *elite – the future engineering leadership which will be able to match or* surpass the best in the global market.

The need for a new approach to education, stressing quality alongside quantity, is needed not only to better meet future needs, but also to prevent the Technion's gradual decline into a "provincial" second-grade engineering school which produces the masses of the "routine" engineers. There are several reasons why such a course is likely to happen should the Technion adhere to outdated policies. First, the Technion has ceased to be the only engineering school in Israel. The universities of Tel-Aviv and Ben-Gurion have large engineering schools, and both Hebrew University and the Weizmann Institute of Science move aggressively into technological areas. The forthcoming highly technological 21st century will force them to move heavily into engineering and specifically into high technology areas. The Technion is geographically remote from the centers of population, and therefore, its only hope to attract the best students and maintain its position in *both* quantity and quality is by an aggressive drive for uncompromising excellence – *excellence of faculty in research and education leading the way to new technologies, and supplying the engineering leadership.* A major drive for excellence affects, of course, not only engineering education, but all Technion policies.

Honors Programs, Creativity and Technological Leadership

The basic idea behind honors programs is the "recognition of the need for able students in all fields to be challenged by the rigor and breadth of honors courses and the intensity and depth of honors research" (30). They not only meet the educational needs of the ablest and most motivated students, but these programs can help discover the future elite of the engineering profession. Moreover, they may be instrumental in renovating teaching practices and learning habits because by their nature, such programs are the fruitful combination of independent study and close student faculty interaction. It is important, however, to note that these programs are not targeted necessarily towards the students on the President's List or on the Dean's List, though many of these students will probably participate in such programs, but in each subject it is targeted toward those students who excel or find interest in that subject. Therefore, many talented students may participate in honors programs though their average grades may not be outstanding. This way, it is hoped, most creative students can be motivated to excel and fulfill their potential. Indeed, experience and research show that the correlation between grades in university and contributions in the profession is rather poor. A broadly-targeted honors program, therefore, has a better chance of identifying the potentially creative students and the future leaders.

Contrary to deeply ingrained Israeli egalitarian notions, honors programs and the fostering of an intellectual elite are democratic in their nature because, as W.D. Weir (31) suggested:

> "What is required in a democracy is not equal treatment in any absolute sense, but the opportunity for every man to realize the promise in him. In the field of education this will mean the opportunity to participate in different programs designed to serve the interests, the talents, the preparations and the motivations of a vast variety of students."

Austin (30), lists the following specific objectives of honors programs:

1. To identify students whose ability and motivation are so high that their academic needs are not adequately met by existing programs.
2. To provide academic opportunities of such caliber that students are challenged to perform at the highest level of excellence possible and to become independent learners.
3. To establish an environment that will encourage the aspirations and achievements of these students and foster dignity, self-esteem and a sense of their potential.
4. To benefit the academic community by focusing attention on good education and on a concept of excellence, giving faculty the psychic reward of working with gifted students, and in attracting to the campus scholars and speakers who would otherwise not be there.

A prerequisite of any attempt to introduce honors programs at the Technion is a reduction of the formal work load on the student, and ensuring a reasonable student-faculty ratio in all departments. Then, it is hoped, the most talented students will participate in certain aspects of the honors programs. By accepting the credits earned in the honors program for a master's degree, the talented student can be positively encouraged to continue his studies and to join industry much better prepared for his job.

Honors programs should consist of special courses, research projects and seminars. Parallel courses in the same subject one for regular students and one for honors students should be discouraged because a class without the best students cannot maintain acceptable standards. Rather, in most courses, the professors could offer an additional seminar in a subject related to the subject matter of the course. In the seminar, the motivated students, those who achieved a certain average in the first examination, could study in depth a certain facet of the subject (for instance, in a fluid dynamics course, a seminar could deal with subjects such as boundary layer theory, turbulence or non-Newtonian flow.) Such a seminar would be based mostly on presentation by students and, being in the specialized field of the professor, it would place very little additional demand on his time. Gifted students could contribute to the overall research in the area through special research projects. Finally, certain graduate courses could be opened to these students as already practiced by several departments. The committee feels that building programs along these lines would involve relatively few additional resources, and that each department could set up, without too much difficulty, honors programs.

The committee feels that the Technion's commitment to honors programs and to fostering a creative elite in the student population serves not only the future needs of Israeli industry, but will also be a clear signal by the Technion to the potential student population, potential faculty and to the rest of the Israeli academic community that the Technion is embarking on a search for excellence, thus increasing the Technion's prospects for attracting the very best students, faculty and industrial research projects.

Perhaps the most difficult part of the process is to convince gifted students that they should try to step out from the "comfort" of mediocrity. This could probably be best achieved by instilling in them the conviction that in the 1990's and beyond, the torch of the pioneering spirit of Israel will be passed on to those who will create Israel's high technological base needed for Israel's survival. Their forefathers had to sacrifice their academic talents to reclaim a barren land, they have the duty to realize their full academic potential to secure all that has been built.

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