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Engineering Education in Israel 1992, in Search of a New Paradigm

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In the twentieth century engineering education has been undergoing a fundamental transformation from an applied and practice oriented curriculum of a professional school, to a science and engineering-science oriented curriculum of a research university. This engineering educational model, should now be reevaluated in light of the needs of twenty-first century technology and industry. In this paper such a model is proposed and the considerations that lead to it are discussed.

INTRODUCTION

ENGINEERING education in Israel began in 1924 when the Technion—Israel Institute of Technology (or Technikum as it was known at the time), Israel's first university, opened its gates. Civil engineering and architecture were the first disciplines that were taught. These two departments, with six professors and twenty-three students have grown in 68 years into nineteen departments, embracing all fields of engineering and science, architecture and medicine—with 10 300 students and over 600 professors. The majority of Israel's engineers have been educated by the Technion, which until now has remained the senior and leading technological-scientific university in Israel.

Israel's higher education system consists of seven universities: Technion, Hebrew University of Jerusalem, Tel Aviv University, Weizmann Institute of Science, Bar Ilan University in Tel Aviv, Ben Gurion University of the Negev in Be'er Sheva, and the University of Haifa. The total number of students in all the universities was 71 000 in 1991. In addition to universities, there are five higher education institutes which are not universities, and a host of regional colleges offering first degrees in various fields.

In addition to the Technion, only two other universities offer engineering education: Tel Aviv University, which has an engineering school with a limited number of disciplines, and the Ben Gurion University which offers a broader range of engineering disciplines. These three universities all provide engineering education at the undergraduate and graduate level to Doctoral degrees in all disciplines.

Although the beginning of engineering education at Technion was rooted in the European tradition, in particular the German tradition leading to the *diplom* degree, in the 1950s the educational system was converted to the American model. Thus, today B.Sc. degrees are granted after four years of study, followed by M.Sc. and Ph.D. or D.Sc. degrees at the graduate level, are the all exclusive norm. The other two universities began their engineers' programs in the American tradition, with Technion faculty being instrumental in setting up some of the programs.

The character of engineering education in all universities is science permeated and, in this sense, it is a reflection of the faculty, which is very similar to a typical faculty on an American research university. In fact, a good portion of the faculty have earned their Doctoral degrees at leading American universities, and they continue to maintain close research ties with their colleagues and advisors there by joint research encouraged by the Bi-National Foundation (BSF)* and also through summer jobs in the U.S.A.

However, towards the end of the 1980s and at the beginning of the 1990s a rather basic re-evaluation of engineering education began in Israel. This has been brought about by three major factors:

(1) a world-wide interest and re-evaluation of the very nature of engineering education;
(2) a grass-roots movement of Israeli junior technical colleges to grant academic degrees (e.g. B.Tech., B.Ed. in Technology);
(3) a massive immigration of engineers from the former Soviet Union.

The world-wide trend in engineering education has been documented in numerous papers, conferences and workshops including a detailed study published as *Engineering Education 2001* [1] which took place at the Technion's S. Neaman Institute,

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* The BSF has an endowment of approximately $100 million which was developed through funding from the US and Israeli Governments. It is administrated by a joint US/Israeli Board of Governors.

followed by a series of workshops. The first workshop [2] took place in December 1986 and was entitled *Engineering Education Meeting the 21st Century*; the second [3] took place in May 1988 and entitled *Innovation at the Crossroads between Science and Technology*; and the third workshop [4, 5], was in June 1989 and called *Reintroducing Design into the Engineering Curriculum*.

The discussion of engineering education that follows draws extensively upon the findings of these studies and workshops.

A BRIEF HISTORY OF ENGINEERING EDUCATION

The first engineering discipline, 'civil engineering' was developed in France in the eighteenth century. It was called 'civil engineering' to distinguish it from 'military engineering' which had been taught and practised for centuries. The other engineering disciplines, triggered by important inventions, branched out from civil engineering. Thus, the invention of the steam engine and the industrial revolution spurred the creation of mechanical engineering; the invention of the electric motor and the applications of electricity spurred electrical engineering, and the invention of the petroleum refinery industry spurred the chemical engineering discipline, and so on.

Engineering education up to World War II was a typical 'professional school', where leading practitioners of engineering taught future engineers current technologies and engineering practice in great detail. Industry and academia were closely linked through the intense involvement of the professors in industrial practice. This can be considered the first stage of engineering education, or the nineteenth-century model.

Engineering education throughout the century but, in particular, since World War II, has been undergoing a fundamental transformation as a result of the permeation of the natural sciences into the engineering curriculum and engineering practices, which brought about a movement toward teaching 'all-embracing fundamental principles', rather than existing engineering practices and current technologies. The engineering education model that evolved can be considered the second stage of engineering education, or the twentieth-century model.

During the same timespan, science and technology, which originate from different historical roots, began to converge and reinforce each other. This process increased the total volume of engineering knowledge immensely and brought about an explosive proliferation of engineering disciplines.

The engineering faculty applied the very powerful scientific methods and tools of science to analyze engineering systems, and formulated the 'engineering sciences' into teachable bodies of knowledge.

Indeed, the core of the second stage of engineering education is preceded by a good dose of natural sciences and an increasing amount of mathematics to cope with the sciences and engineering sciences.

The 'scientific revolution' in engineering education and the twentieth-century model thereof, expanded engineering capability and made it possible to sustain an ongoing technological revolution for decades. It must be viewed, in historical perspective, as a great success. But, it also had some inherent flaws and undesirable by-products. To begin with, the movement toward the sciences was also motivated by the desire of faculty for academic respectability, in terms of the prevailing norms of the general culture of the university, which called for subject matter that was intellectually tough, analytic, definable and teachable. It is not surprising, therefore, that engineering design or 'synthesis', though the central theme of engineering activity, perceived as intellectually soft, intuitive and informal was by-and-large purged from engineering curricula. Moreover, the desire of the academic community to deal with problems that had mathematical rigor, and were quantitative, frequently restricted them to oversimplified engineering problems of limited relevance to real systems. However, this did not create any dichotomy in the minds of faculty members since the vast majority of them were, by this time, far removed from industrial practice. In fact, they became more professors of applied science than professors of engineering. The classical career path of a current engineering faculty is to apply for a teaching position in a university immediately after obtaining a Doctoral degree, totally avoiding industrial experience, which has usually been viewed as a 'career block' rather than a 'career boost'.

The twentieth-century model, therefore, has resulted in a situation whereby a faculty consisting mainly of non-practicing applied scientists, teach and educate future practising engineers, via a curriculum which is best suited for academic research, while considering publishable research as the main academic objective. Indeed, promotion is dominated primarily by the quality and quantity of published research.

In this educational model industry had to complete the educational process by teaching engineers design, current technologies and current engineering practice, as well as providing continuing education. Industry accepted this educational model, because it provided engineers with a sound and broad foundation of vital engineering principles on which further, more focused and meaningful (for industry) engineering know-how could be built.

TOWARD A NEW ENGINEERING EDUCATION PARADIGM

But, three globally interwoven developments, which have been gaining momentum since the seventies, now necessitate a new transformation of engineering education; the development of a third stage model which should appropriately be termed the twenty-first-century model. This model should not only remove the flaws in the previous model, but should also answer future needs. The developments are:

(1) the globalization of the economy, markets and manufacturing;
(2) the fusion of science and technology into a sometimes indistinguishable entity;
(3) an all-overriding, profound computer revolution.

As a result of the first development, which spurs fierce global competition, partially educated engineers by 'non-practitioners' will become less desirable and acceptable to industry. The second development renders a partial return to the first stage, vocational and more practice-oriented education—as advocated by some—to be unproductive and wrong; whereas, the third development, the computer revolution, will provide the crucial elements of the third stage model. Indeed, 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 range of real problems with all their complexities, thus bringing industry and academia closer, 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 in a formalizable teachable body of knowledge.

The program to create a third stage twenty-first-century engineering education model, in the view of this author, should consist of two interconnected elements:

1. An extension of the engineering study program to five years leading to a Master's Degree.
2. A drive to appoint to engineering departments a significant number of design, manufacturing and industry-oriented faculty.

TOWARD THE TECHNION THIRD STAGE ENGINEERING EDUCATION PROGRAM

The five-year Master's program

The basic premise of the proposed third stage engineering program is that the science-permeated curriculum was an outstanding success and should not be abandoned but improved. We cannot, as some suggest, go back to a practice-oriented professional school. In Israel, for example, we see the inevitably rapid obsolescence of such education among some of the Russian immigrant engineers who had a far more technology-focused, specific practice-oriented education. Neither can we introduce significant elements of design and production over all four years of study, as suggested by others, because our curriculum is crowded. It is in fact overcrowded by the essential fundamentals of the sciences, mathematics, engineering sciences and computer technology, although efforts should be made to incorporate some design elements along the way. Finally, we do not want to teach fundamentals on a need-to-know basis while tackling real engineering projects, because such a method is inefficient and is bound to leave large gaps in basic knowledge.

However, we do want to complement the current science-based education with design and production knowledge. We want to show the students how the fundamentals they have learned are to be used in real cases, we want to teach them integration, synthesis and team work, we want to teach them the limitations and constraints, such as in time, resources, and hard available data, of real engineering problems, we want to teach them efficient communications, reporting and elements of management, and finally we want to teach them the social and environmental implications of their work.

In order to accomplish these goals we must add one more year of study leading to a Master's Degree, and we must develop and hire faculty who are design-oriented and well connected to industrial practices.

The Master's Degree should become the entry level to advanced engineering fields of activity, and the programs should have a carefully focused engineering content. A reasonable initial target is to encourage the upper half of the graduates to continue their studies for a fifth year toward a Master's Degree. The other students will leave the university with a Bachelor's Degree as usual. We do not suggest two different parallel routes toward engineering degrees, one with a Bachelor's Degree and one with a Master's Degree, but one single route, which can be terminated after four years with a Bachelor's Degree, or continued for one more year to a Master's Degree.

The fifth year studies should be carried out within the framework of the graduate school, culminating in a M.Eng. degree rather than the M.Sc. Degree. The difference between the two are that the latter contains a significant research program, it lasts at least two years and should become the pathway to Doctoral studies; whereas, the former will be engineering, design and production-oriented. It can be strictly discipline rooted (e.g. Mechanical Engineering, Chemical Engineering, etc.) or can be a blend of any engineering or science discipline with a multidisciplinary technology (e.g. optoelectronics, biotechnology, water technology, plastics engineering, material engineering, quality assurance, environmental engineering, artificial intelligence and robotics, etc.) The programs must be developed from the basics by the academic departments.

It is important to stress, that the studies in the fifth year will not be heuristic or vocational in nature, but they will be fundamental though engineering-oriented, stressing synthesis, integration, design, production, management, and team-work. The advantages of the proposed program are manifold:

1. The program will yield a far more mature industry-oriented engineer ready to compete in the twenty-first-century international scene.
2. It will permit a long overdue, slight reduction in study load in the undergraduate program. This will be acceptable because most better students will opt for the fifth year thus ending up with a broader knowledge than the current graduate; whereas although the others will leave with slightly reduced study load, it will be hopefully better digested and understood.
3. Co-operation with industry will increase.
4. The program is fully compatible and complementary with the drive to establish multidisciplinary centers of excellence at technological universities.
5. The stress on engineering design and manufacturing in the proposed programs, will strengthen the orientation of the faculty, making engineering education more balanced. This last point is an important component of the third stage model.

Faculty development

In the third stage engineering education, the engineering sciences will remain the core of the curriculum, but as stressed by Shinnar *et al.* [4, 5] we must recognize that the engineering sciences are fundamentally different from natural sciences in that they require a strong feedback from engineering practice. Otherwise, there is a danger that the focus will shift to areas and problems which have no possible use, as intellectually interesting as they may be. The engineering school, in its twenty-first-century version, should remain a professional school. In this sense it is similar to the schools of medicine and law. Foremost, it must educate engineers for industry, where they will be practising technology. And, in the same way that medicine and law schools retain top level practitioners, so must the engineering school find the right way to keep in touch with engineering practice. This is possible only if some optimal fraction of the faculty has a deep understanding of industrial practices. This faculty can yet fulfil an additional important function of providing a role model for students, creating much needed ties to industry. One possible model for the future engineering school is the medical school in which faculty consists of basic scientists, applied scientists, academic clinicians and hands-on clinicians. There is, of course, an essential difference. The primary place to practice advanced medicine is in the teaching hospital of the medical school, which is certainly not so in engineering. But, used with caution there is still a place for analogy. The academic practitioner in medicine provides a bridge between the advances of science and medical practice. He also has something that an excellent hands-on clinician may lack, namely the ability to translate his approach into more general principles. There is a need for a similar faculty in engineering.

In order to facilitate the third stage engineering education, the fraction of faculty with strong engineering and design experience should be increased, and there should be a specific carefully planned policy to search for and develop such faculty members, and to maintain a proper mix of faculty in each department.

There are two sources of such faculty members: the first is experienced engineers from industry, who have shown during their careers that they have the intellectual capabilities that allow them to function in an academic environment. The second is from the younger members of faculty who wish to devote their efforts into a design-production orientation. The cultivation of the former requires changes in hiring and promotion criteria, whereas the latter requires a planned university program. This is important because development of young faculty in this direction requires industrial involvement; additionally this type of development has a longer incubation period than the standard science-oriented careers.

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