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Personal View: Engineers for a New Age: How Should We Train Them?

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The paper offers the perspective of the senior executive of a US manufacturing corporation into the issue of engineering education and training. It is based on the author's extensive international experience in recruiting, training and working with engineering personnel educated in universities from various countries. The article reviews the impact of the current scientific and technical revolution on the society, business corporations and engineers. It describes the new expectations that high-technology companies have of their engineers and identifies the need for a fundamental change in the current approach to engineering training. The author supports the view of short undergraduate education programs followed by life-long training and upgrading activities. A new 'spiral curriculum' for undergraduate studies in electrical engineering is proposed and described. The importance of cross-disciplinary education at undergraduate level is analyzed with respect to the need to stimulate future engineering entrepreneurs. The article highlights the importance of computer literacy to tomorrow's engineers, and reviews the main issues related to computer-aided education programs. It lists representative electrical engineering software packages that students should train with in order to have adequate work proficiency when joining industry. The article concludes with a call to using innovative approaches to create and maintain the resource base necessary to support effective CAE programs.

1. A WORLD IN TRANSITION

WE LIVE in a world in transition. Profound and rapid changes take place around us in all spheres of human endeavor. These changes range from rapid advances in science and technology, to breakdown of economical, social and political structures, and to alteration of moral values. The change process is oblivious to geographical boundaries and reverberates with varying intensities in all nations on earth.

What is the fundamental cause for such deep and fast-paced development? Many people believe it is the technology revolution. Scholars of anthropology consider that the world is presently undergoing the post-industrial revolution, fueled by the explosive growth in applied sciences and technology. Advances in technology are credited with allowing mankind to grow more food, create better goods and services, improve health, travel faster and communicate simultaneously. Technology has a tremendous impact on everything we do, and influences our behavior and way of thinking. Technology creates new technologies, feeding upon itself in a never-ending spiral of fast-paced evolutionary development. Beside the benefits it brings, however, technology is also blamed for many uncertainties and negative side-effects on society and the environment.

Who are the people, organizations and forces that create technology, make it work and disseminate it? They are scientists, engineers, technicians, skilled workers, businessmen, entrepreneurs and financiers whose creativity, hard work and dedication make things happen. They organize themselves in dynamic companies which conduct fundamental research, develop new products, fabricate, distribute and utilize new technologies. Private investors, financial institutions and banks provide the necessary capital to setup and run companies. The forces that help technology disseminate are those of the free market economy and government policies. The symbiotic yet dynamic relationship between these fundamental factors fuels the current technical revolution. As a result, we see a world in a continuous state of change, and this process is only going to accelerate in the future (Fig. 1).

The world of tomorrow is expected therefore to be one of even faster changes and greater uncertainties. It has been called the 'post-industrial society' or the 'information age' to acknowledge its breakaway from the three-century-old industrial era, and to welcome the arrival of the information revolution. Let us outline its main features as they relate to technology, market forces and the people who take part in it. First of all, at the applicative sciences level, unprecedented advances and breakthroughs are anticipated. The fields of microelectronics, material sciences, molecular biology, artificial intelligence are just a few examples of areas of fast-paced progress. As a result tremendous opportunities are

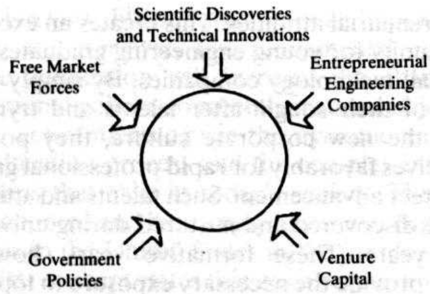

Fig. 1.

created to develop and commercialize new products and services. These opportunities are seized by aggressive high-technology companies which move rapidly to meet emerging market needs. Secondly, the economic activity in the world becomes increasingly transnational and much more competitive. This is the outcome of the expansion of free market economies and implementation of governmental policies to reduce trade barriers. We will see more products being designed in one country, manufactured in another and marketed worldwide. Increased competition will force many companies out of business, yet many more will emerge or adapt themselves to the new business climate. Thirdly, new technology companies will be founded, managed and staffed by a new breed of engineers and specialists. These people must possess new skills and attitudes to perform effectively their challenging and diversified tasks. Although new technology companies will proliferate rapidly, their initial failure rate is expected to be high, and the surviving companies will undergo many transformations during their lifecycles. As a result, engineering jobs generated by such corporations will be plenty, but of an uncertain duration.

2. WHAT DO CORPORATIONS EXPECT OF THEIR ENGINEERS?

Business corporations will be fundamentally affected by all these factors. Companies that survive the competitive environment become much more flexible, more dynamic and exhibit new sets of values. They are called 'reinvented' corporations because they have important new features that distinguish them from their predecessors. These features include a prevailing philosophy of being market driven; staying very close to customers in a mutually advantageous partnership; maintaining a small size; adopting a flexible, horizontal-type organizational structure; using a management style that emphasizes coaching and motivation; developing a corporate culture based on entrepreneurship; rewarding individual initiative; encouraging personal development; providing proper wages, benefits and profit sharing to all employees; and fermenting an atmosphere almost of obsession with the quality of the products and services offered.

Numerous such innovative organizations spring up every year in America, and quite a few of them become symbols of success in their fields almost overnight. Names such as Microsoft, Intel and Apple Computers are well known to everybody today, yet these now-powerful corporations were fragile and struggling small businesses only a decade or so ago. Other new companies such as Symmetrix, Digidesign and Fiberoptic Technologies are less than five years old, but they have experienced tremendous growth and are on their way to spectacular achievements. The same process of genesis and growth of new-style corporations takes place with varying degrees of success in most countries of the world, in direct response to the prevailing economical, social and political conditions. It can be said, therefore, that the process of 'reinventing' the corporation is truly a global phenomenon.

Technology corporations require a new type of engineer with new skills and attitudes. It is a known truism that the performance of any company is in direct relationship to the skills, effort level and attitudes of its people. Therefore, if a company sets up certain performance criteria for itself, it must by necessity establish matching standards for its people. What are the norms that a technology-based dynamic corporation requires of its staff? What expectations are being placed on its existing and yet-to-be-recruited engineers? Specific answers may vary from industry to industry, but there is a strong consensus among executives that three areas are equally important: know-how, skills and attitudes.

Engineers are expected to have breadth and depth in their scientific and technical knowledge. They should understand the interrelationship between various engineering fields, as well as their direction of development. Principles of scientific investigation and methodology of engineering design should be well mastered. Additionally, engineers must know how to address fundamental business issues such as sales and marketing, economics, management, profitability, financing, customer satisfaction, competition, business risks, taxation, government regulations, law, etc. It is also required that they should be aware of society's concerns regarding environmental protection, impact of technology on ordinary people, and so on.

Computer literacy has emerged as one of the most important new skills required of engineers nowadays. It includes not only knowing how to use business and engineering application software packages but also typing at 50 words per minute! A recent survey conducted by the IEEE (*Spectrum*, May 1993) found that 96.5% of US electrical engineers use personal computers either at work or at home. The computer has become, therefore, a widely used engineering tool and every engineer is expected to know how to use it effectively. Another important skill of the engineer is his/her ability to communicate well, orally and in writing. Companies also expect their technical staff to work well under pressure, have pleasant personalities, be of good character, make excellent team players and be able to adapt to changing business conditions.

Yet it is the area of attitudes and values where corporations are making a dramatic shift in their expectations. Modern companies view their skilled talent as their most important asset base, and want their people to be united by a commonly shared set of values known as the corporate culture. It is this new corporate culture that engineers must match with their own attitudes. Which are these new attitudes? They include: a profound sense of loyalty, dedication and commitment to the goals of the corporation; hard work, optimism and high energy level; active entrepreneurship, initiative and leadership; being proud of the company; and a permanent awareness that the company must be financially successful.

3. TECHNICAL ENTREPRENEURSHIP—THE NEW BUSINESS MENTALITY

A new mentality has been developing in the American business community in the last two decades. It is the mentality of technical entrepreneurship whose goal is to create wealth through application of emerging technologies. This mentality emanates from very special individuals who have the vision, courage, talent and determination to start and successfully complete the risky and difficult task of developing and commercializing new technologies. In sharp contrast with their predecessors, today's technical entrepreneurs create wealth by using the power of the human mind rather than exploiting earth's natural resources. The names of Bill Gates (Microsoft), Ross Perot (EDS) and Steve Jobs (Apple) have become synonymous with enormous financial success because they founded hugely successful companies based on their own technical knowledge and entrepreneurial spirit.

All newly 'reinvented' technology corporations have been founded or reorganized by technical entrepreneurs. The corporate culture of these organizations is highly entrepreneurial, in direct reflection of the values-set of their leaders. it is generally characterized by a state of continuing change—sometimes perceived as chaotic—yet with a sharp focus on total customer responsiveness. Everyone in the company is encouraged to promote new ideas and methods to improve quality and productivity. Individuals take charge of their own initiatives and are rewarded handsomely if successful. Direct and open communications among team members creates a work environment that is stimulating, pleasant and productive. The boss–subordinate relationship is being replaced by a new situation in which the person in charge is an active team member as well as its coach.

Owners and managers of entrepreneurial companies are on constant lookout for people with entrepreneurial attitudes. This creates an excellent opportunity for young engineering graduates joining small technology companies. By simply being aware of their sought-after talents and trying to match the new corporate culture, they position themselves favorably for rapid professional growth and career advancement. Such talents and attitudes may be discovered and nurtured during university study years. These formative years, however, should provide the necessary exposure to topics of entrepreneurship. One should not forget that the successful technical entrepreneurs of tomorrow can only emerge from the existing pool of engineering students of today. It is highly desirable, therefore, that academia, industry and government recognize this new phenomenon and work together to develop effective policies for training future technical entrepreneurs.

4. TRAINING TOMORROW'S ENGINEERS TODAY: A CALL FOR CHANGE

The engineering training process has historically been based on a fairly stable body of knowledge in natural and applicative sciences. It was also founded on the assumption that societal and technological development processes were taking place in a predictable and controllable manner. However, the last few decades have shown that those assumptions were largely incorrect. The body of human knowledge has been experiencing explosive growth, particularly in the fields of applicative sciences and technology. And the stability of social and economic orders has been proven to be just an illusion.

How, then should today's engineering education be structured to meet the demands of tomorrow's society? This topic is the subject of numerous studies, controversial reports and lively debates in the academic, industrial and government circles in many countries. Although many differing views are being offered, there is one area in which there is full agreement among participants. The consensus is that the engineering education process must change to respond adequately to the new needs of society.

There are three fundamental objectives that any modern engineering education and training policy must achieve. Firstly, it must provide students with knowledge that has enough breadth and depth. This task has traditionally been fairly well done by many institutions of higher technical education. Secondly, it must ensure that engineering training meets the demands of tomorrow's corporations. It is in this area that most industry executives believe that academia has failed in the past. And thirdly, it must provide the engineer with a better foundation to obtain employment, and with a readily available infrastructure to upgrade his/her skills over a lifetime period.

To satisfy completely all the above demands in a fast-paced technological and economic environment is a very difficult task, if not an impossibility. There are, however, two fundamental concepts whose application will increase the chances of educational policies to meet their stated objectives. These concepts recognize the dynamic nature of the education process and the complex interrelationships that exist in today's society. They have been adopted and have enjoyed various degrees of success in the United States in the past few years. The first concept states that engineering education should be based on a short basic university training program followed by a lifelong continuing education process. The second concept calls for academia, industry, professional associations and government to co-operate fully in the formulation and implementation of engineering training policies.

The January 1992 issue of the IEEE *Spectrum* magazine lists specific recommendations for changes in undergraduate engineering education in America. They were prepared during the 1980s by six prestigious US entities such as the National Science Board, IEEE Centennial Forum, Accreditation Board for Engineering and Technology, etc. Recommendations include: more interdisciplinary courses; more emphasis on engineering design, manufacturing and concurrent engineering; more use of computers and computer-aided instruction. Curricula innovation programs following these recommendations are presently being implemented at leading American technical universities such as Carnegie Mellon, Cornell, Texas A&M and Stanford.

The main drawback of the traditional undergraduate curriculum is that it consists of a rigid sequence of courses that are too narrowly focused and compartmentalized. The proposed new approach, sometimes called the 'spiral curriculum', would smoothly interweave mini-courses in the fundamental sciences, engineering and social sciences throughout a student's academic years. For example, various areas of electrical engineering are revisited to provide new depth and understanding of the relationship between them, while at the same time introducing new analytical experimental tools. This concept of integration spans both horizontal, i.e. interdisciplinary, and vertical dimensions, uniting precollege education, undergraduate studies and continuing education programs (Fig. 2).

Any undergraduate university education program based on this approach should be short in time, spanning no more than seven or eight semesters, yet intense and broad in training. The objective is to provide the student with broad basic knowledge in the engineering field of choice. Areas of concentration of technical studies are desirable, but specialization should be avoided. The curriculum should be flexible to meet each student's individual needs, and definitely include co-operative work programs in conjunction with industry. A credit point system should ensure that the graduation requirements set forth by the university are

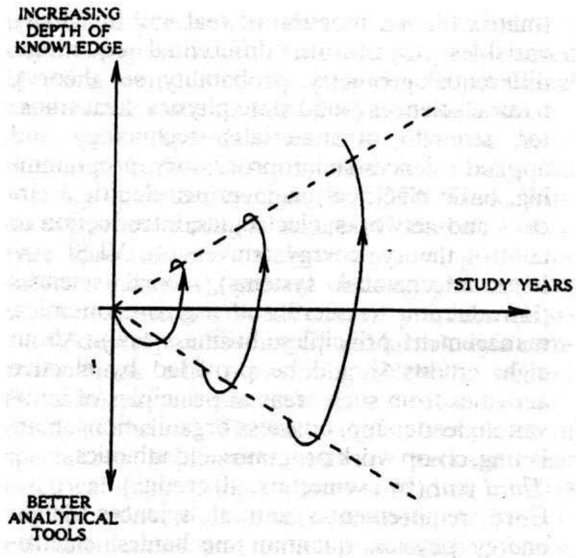

Fig. 2. The 'spiral curriculum' concept.

being met, yet the individual student aspirations are also fully satisfied. The curriculum should consist of a mix of core subjects and electives in the fields of mathematical and natural sciences, technology and applied sciences, philosophical thought, social and behavioral sciences, language, communication and physical education.

Credits are accumulated by meeting the requirements of a variety of full courses, minicourses, lectures, seminars, laboratories, individual studies, examinations, co-operative work programs, R&D activities and theses, each activity being assigned a basic credit rating by the faculty. As students work their way towards graduation, increasingly higher importance is attached to hands-on training activities such as laboratories, computer programming, co-op work and R&D programs, as well as economics and business management.

The new approach is illustrated in the following curriculum proposed for an undergraduate degree (bachelor) study program in electrical engineering.

- *First year* (two semesters, 30 credits required) Core requirements: mathematical sciences (fundamentals of algebra, trigonometry, calculus), natural sciences (fundamentals of chemistry, physics, earth sciences, astronomy), technology and applied sciences (introduction to computers, programming methodology, dynamics, electric power and electronics, science of materials), philosophical thought (introduction to philosophy, philosophy of science, religious cultures), social and behavioral sciences (anthropology, elementary economics, human relations, political science), language and communication (public speaking, debates, literature). The core requirement credits should make about 85% of the total credits necessary, the balance being provided by electives from the fields of arts, foreign languages and athletics.
- *Second year* (two semesters, 35 credits required) Core requirements: mathematical sciences

(matrix theory, function of real and imaginary variables, transforms, differential equations, differential geometry, probability, set theory), natural sciences (solid state physics, heat transfer, strength of materials), technology and applied sciences (microprocessors, programming, basic electrical engineering, electrical circuits and networks, electronics, introduction to control theory, energy conversion, VLSI systems, mechanical systems), social sciences (introduction to micro and macro economics, management principles, business law). About eight credits should be provided by elective activities from such areas as principles of innovation, leadership, business organizations, marketing, co-op work programs and athletics.

- *Third year* (two semesters, 40 credits)
  Core requirements: natural sciences (high-energy physics, quantum mechanics, electromagnetic fields), technology and applied sciences (computer architectures and networks, software engineering, electromechanical energy conversion, electrical power generation, transmission and distribution, digital signal processing, electro-optics, digital electronic circuits and network design, introduction to process control and instrumentation, telecommunication networks), social sciences (principles of business management, role of technology in society). Elective credits from areas of advanced mathematics, computer and software sciences, management, finance, cross-disciplinary fields, technical entrepreneurship, athletics, co-op work programs, etc., would complete the credit criteria for the third year.
- *Fourth year* (one semester, 35 credits)
  The student selects the area of concentration and the subject of graduation thesis to meet his/her individual needs. Following curriculum assumes electrical controls as the area of concentration chosen. Core requirements: advanced theory of control systems, software engineering, digital and microprocessor-based control systems, process control and instrumentation, graduation thesis. Elective activities may include co-op research programs, issues of private engineering practice, technical entrepreneurship, creative problem solving, and so on.

After the successful completion of the undergraduate study program, the engineer starts his/her professional career by joining a private corporation, public organization or government agency. Based on his/her individual circumstances, he or she may decide to continue his/her education by registering for a graduate study program (master's) or just take selected courses in disciplines of interest. A typical graduate study program would span over three to four semesters, and should be tailored to meet the engineer's specific requirements. There are only two major directions which engineers should choose from at this point in their career: one is technical specialization, the other one is orientation toward business administration and management. Should the engineer decide to pursue technical specialization, his/her master's program will be focused on the specific area in which he or she works or conducts R&D activities. Credits are obtained by meeting the requirements of the study subjects and activities defined at the outset of the program, and by presenting a thesis or dissertation in the chosen field. Master's programs should include substantial input from industry, both in terms of orientation as well as resource support (laboratory facilities, collaborative R&D programs between academia, corporations and the government, financial backup, scientific and technical know-how, etc.). Most post-graduate (doctoral) study programs which pursue further technical specialization would follow the same principles as a master's, except that the area of specialization becomes much narrower, yet the depth of the expertise acquired is far greater.

A much more unconventional situation arises when the engineer decides to obtain a master's degree in a non-engineering field, most likely business administration, finance, accounting, law or economics. Yet it is precisely this kind of cross-disciplinary education that produces the type of professional who can best deal with the challenges of a complex and dynamic environment.

From an industry perspective, only such professionals become capable of leading other people effectively, and thus become the driving force that makes things happen in each corporation. This view is supported by the fact that a large number of executives of successful US technology-based organizations are individuals with cross-disciplinary training. From the engineer's perspective, his/her chances of pursuing a professionally successful and financially rewarding lifelong career are largely increased, since his/her skills become so much sought-after by potential employers. Such people are also in a very privileged position to start up, own and manage the growth of new companies which seek to develop and commercialize emerging technologies.

Long-range continuing education programs require several key characteristics in order to be efficient. They include: close relationship between academia, industry, professional associations and government; flexibility to accommodate the needs of individual students; focus on technical specialization or cross-disciplinary training; provision for retraining and education update opportunities. A major role in ensuring the professional and ethical standards of the engineering community should be played by national engineering certification, licensing or registration bodies. Such organizations are legislated at the provincial or state level with a mandate to regulate the engineering profession, particularly engineers in independent practice. Their statutes normally cover issues related to qualification requirements for registration, certification as engineer-in-training, examinations, legal definition of the profession, self-organization, rules for practice of professional engineering, fees, prohibitions, penalties and disciplinary proceedings.

5. USING COMPUTERS TO EDUCATE ELECTRICAL ENGINEERS

The last decade has witnessed a vigorous proliferation of computer-aided education (CAE) programs at all levels of the US education system, starting from elementary grades throughout high-school, undergraduate training and to doctoral studies. A large variety of CAE software programs have emerged which help students of all ages to acquire computer skills for general-purpose, business or specialized training. Computers are also widely used in education institutions for administrative purposes such as class scheduling, record keeping, communications and budgeting.

The rapid acceptance of CAE methods is generally attributed to several important benefits that they bring to the training process: they take less time, therefore reduce costs; are more effective and versatile; provide higher-quality instruction; and are preferred by students. However, practical implementation of CAE in the United States has experienced some serious problems. They relate mainly to inadequate computer training of educators themselves, insufficient funding for hardware, inappropriate software programs, and poor planning and preparation. The general consensus appears to be that CAE should not be viewed as the solution to all problems faced by the educational system, but rather as a powerful tool that integrates well into the overall education policy.

Training of electrical engineering students lends itself particularly well to using computers due to the very nature of the fields of study. Data processing, numerical matrix computations, electromagnetic fields, electrical and electronics circuit design, automation, control theory and programming languages are all representative examples of areas where computer-based methods are widely used. It is precisely in these areas that industry expects engineering students to be properly trained in using computers. As a minimum, electrical engineering students should acquire skills, knowledge and experience in the following basic domains: keyboard typing and data entry (50 w.p.m.), operating systems (MS-DOS, Unix, Windows), programming languages (C, Pascal), Lotus-type spreadsheets, database processing systems (dBase, Informix), general drafting (AutoCAD), word-processing (WordPerfect), graphics (Harvard), desktop publishing (PageMaker), data communications and networking (Novell), utilities (Norton), project management and resource scheduling (Timeline). The following is a sample list of specialized application software packages that electrical engineering students should be familiar with: Mathlab, Mathematica (symbolic mathematical calculations and data visualization), Ansys, Cosmos (electromagnetic analysis), ProtoSim, HiQ (modeling, analysis and simulation of dynamic systems), Design Centre, PSPice (simulation of logic circuits), DSPworks, Integrated Systems (digital signal processing), Comnet (communication network design and simulation), Omega Engineering, Intelligent Instrumentation (process data acquisition).

Creating the hardware and software base necessary to train engineers raises serious funding and operational issues for the faculty. It seems that public universities never receive enough funds from the government to implement all their computer-based training programs. Therefore innovative approaches should be used, such as asking for donations of equipment, software and capital from industrial corporations and individuals, participating in joint R&D programs with businesses in order to generate funds, collecting and refurbishing used equipment, etc. From an operational viewpoint, the faculty should ensure that its educators (assistant professors, instructors) are properly trained in the use of CAE tools and that adequate service contracts are in place to maintain the hardware base fully operational.

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