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Viewpoint: General Practice Engineering*

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Medicine, law, dentistry—all have common first degree programs, but not engineering which fragments its undergraduate programs into disciplinary branches beginning in first or second year. It is suggested that today's complex and sophisticated industry requires broadly educated graduates capable of working in an interdisciplinary environment, and to satisfy this need the establishment of 'general practice engineering' programs is proposed. The prospect for acceptance of such programs is discussed in the context of the overall training of engineers, including the industrial apprenticeship phase.

INTRODUCTION

ENGINEERING undergraduate programs have traditionally been specialized along disciplinary lines, with differentiation beginning in first or second year. This model is in striking contrast with the practice in the undergraduate programs of the other major professions: medicine, law, nursing, dentistry, which have undifferentiated undergraduate programs. Specialization in these professions only occurs subsequently, through formal or informal apprenticeship.

The typical training and career path in engineering is an undergraduate degree in one of the recognized disciplines (e.g. chemical engineering, civil engineering), followed by a form of unofficial industrial apprenticeship in which the graduate receives on-the-job training by working under the close supervision of experienced engineers. This phase can last for a number of years, and is recognized by the professional associations most of which require several years of relevant industrial experience as a condition of admission. An alternative career path involves specialized post-graduate training in a university leading to a post-graduate degree; however, it should be noted that the professional associations generally do not accord full recognition to post-graduate academic experience, and that some industrial experience is usually required as a condition for professional licensing.

In the medical profession a general first degree may be followed by a two-year residency in family practice in a hospital, leading to a licence to enter general practice. Alternatively, to practice a medical speciality a four-year hospital residency is required. These forms of post-graduate training are somewhat similar to the post-graduate apprenticeship in the engineering profession, involving work performed under the direct supervision of an experienced practitioner. The most important difference between engineering and medicine is that the post-graduate apprenticeship phase in engineering is structured informally.

Law school curricula generally consist of a set of compulsory courses supplemented by a specified number of electives which permit some degree of voluntary specialization, but usually this is not recognized in the diploma. Within some jurisdictions the graduate is required to article before being licenced; however any specialization at this stage is fortuitous and is entirely due to the nature of the law firm with which the articling occurs. Expertise in the legal specialities, such as tax law, corporation law, criminal law, etc., is obtained informally through years of practice in these fields, usually in collaboration with experienced practitioners.

It is of interest to know whether the differences in the educational models followed in engineering and its sister professions originated mainly for historical reasons, or whether they arose for substantive reasons. It should be noted that specialization at the undergraduate level leads to multiplication of course offerings, and also to substantial administrative overhead costs attributable to departmentalization, which might otherwise be avoided were all undergraduates taught a common curriculum.

HISTORICAL PERSPECTIVE

The reason for a single undergraduate curriculum in medical education is obvious: the human body is a highly complex system in which the various components interact with each other in numerous direct or subtle ways. For instance, the practice of psychiatry requires a comprehensive knowledge of medicine, because of the interactions

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of the brain/mind with the body, particularly with its biochemical and enzymological systems. The only exceptions pertain to certain peripherally related fields, such as midwifery and chiropractice, in which full medical training is replaced by a shorter, more specialized curriculum.

The failure of the law schools to offer specialized programs may be an artefact of history. Undoubtedly most aspects of the practice of law have become more complex over the years; this is particularly true of corporation law and tax law, but it probably also holds for other fields. However, the pattern of a single curriculum, which was set in an earlier and simpler period, was retained. It should be noted that a common curriculum has the advantage from the point of view of the graduates that their choices and opportunities are not restricted when they enter the workforce. Also, the law schools undoubtedly find it easier and more economical to offer a single general program rather than a suite of structured, specialized programs.

For historical reasons higher education in engineering became fragmented at its inception. Starting with civil engineering, various professional discipline-based engineering societies were founded in the nineteenth and early twentieth centuries, and it was then natural for educational programs to be split on a similar basis. The objective at the time was to graduate a 'finished' engineer, which in the early days, at least for the theoretical aspects, was feasible provided that the training was concentrated and specialized. Consequently, engineering programs have traditionally been compartmentalized along disciplinary lines, although some schools have a common first year and may also have some common courses in the senior years.

DEFICIENCIES IN CONTEMPORARY ENGINEERING EDUCATION

The situation in industry has changed beyond recognition since the first university programs in engineering were instituted, and it behoves us to ask whether the fragmentation of programs into disciplinary specialities, which was appropriate at that time, is still valid in today's more sophisticated world. There are indications that engineering education as currently structured is in need of reform [1,2]. A part of the problem relates to undue emphasis on analysis at the expense of synthesis, and to rectify this deficiency consortia of US universities (Synthesis Coalition; Foundation Coalition) are developing new curricula and new methods of instruction which emphasize design and integration of knowledge.

Another deficiency in contemporary engineering education relates to undue specialization of undergraduate curricula. This has been recognized in major reports on engineering education, which explicitly stress the need to reduce the amount of specialization. For instance, the ASEE's report entitled *National Action Agenda for Engineering Education* [3] states: 'To focus the undergraduate program on its goal of providing the tools for lifelong learning, much of the current disciplinary specialization should be postponed for graduate study.' A report prepared by the Canadian Council of Professional Engineers/National Committee of Deans of Engineering and Applied Science [4] recommends that 'undue specialization should not occur at the undergraduate level. Specialization is more appropriately introduced at the graduate level'. A British report written by the Educational Policy Committee at the 1991 Engineering Professors' Conference [5] recommended reducing the load of factual material that students have to learn (mostly material of a specialized disciplinary nature) and concentrating on fundamentals of engineering and on acquisition of key transferable skills. The Canadian Academy of Engineering [6] goes even further in stating: 'In Canada and elsewhere, students choose a particular discipline in engineering (civil, chemical, electrical, mechanical, etc.) either on entry or in an early year. This limited degree of differentiation has served the profession and the community well, but the appropriateness of this differentiation must be continuously examined.'

There are a number of reasons why the current paradigm in engineering education is in need of reform. Firstly, the current programs are not delivering graduates with a sufficiently broad, interdisciplinary knowledge and outlook to allow them always to operate effectively in the complex contemporary industrial milieu. Secondly, the enormous diversity of products and processes in today's industries makes it impractical for the universities to produce graduates with specialized training appropriate to each situation. Unfortunately the unrealistic view held in many academic quarters that their graduates are expected by industry to have, upon graduation, the knowledge and abilities of competent engineers has led to excessive padding of curricula with specialized technical subjects, and to the relative neglect of important other aspects of education, particularly key transferable skills such as the ability to communicate, to work in teams, to learn on one's own, to synthesize, to solve problems, etc.

It is not generally appreciated how little of the specialized material included in upper-year undergraduate curricula is used by the average graduate, but the evidence bears this out. For instance, a British study [7] found that only 41% of graduate engineers employed by two medium-sized firms thought their degree was useful in the performance of their job. An analogous American study [8] also reported that many engineers found little use in their work for the knowledge acquired in their undergraduate training.

At the author's institution returns from two questionnaires, one conducted on graduates who had been 3–5 years in the workforce, and the other on employers, support these findings. The graduates reported that on average, on a course-by-course basis, over the previous year they had used only approximately 10% of the technical material studied in the last two years of their program. This accords with a survey on frequency of use of mathematical subjects by electrical engineering graduates of the University of Alabama [9]. These survey results as well as the findings of the British and American studies alluded to above do not mean that advanced technical subjects are not important; rather they indicate that most engineers find that only a small fraction of the specialized theoretical subjects taught in the senior years of their academic program is useful at their employment.

The employers were asked to select from a list of attributes the three most important qualities they sought in hiring engineering graduates. Forty-three percent did not include 'technical knowledge' in their selections. (The most sought-after attribute was 'ability to communicate', selected by 81% of the respondents). It seems probable that employers assume that all graduates of an accredited engineering school have a basic knowledge of the fundamental principles in their discipline, and that many employers are not interested in their more specialized knowledge.

In summary, it appears that current engineering academic programs put too much emphasis on relatively specialized analytical subjects which are frequently of limited utility in the workplace, and too little on creating breadth of knowledge and outlook, and on teaching general skills and design capability.

THE CASE FOR A GENERAL PRACTICE ENGINEERING PROGRAM

'General Practice Engineering' is proposed as the name for a completely general, non-specialized undergraduate engineering program. Its curriculum would consist of basic courses taken from a variety of existing programs, including:

- graphics
- statics
- dynamics
- thermodynamics
- structures,
- electric circuits
- electrical machinery
- controls
- heat and mass transfer
- fluid flow
- computer programming
- introduction to materials.

These basic courses would be supplemented by interdisciplinary and foundational courses in:

- mathematics
- physics
- chemistry
- microbiology
- the humanities
- law
- ethics
- business
- communication
- environmental science.

The program derives its appellation from general practice in medicine, although it should properly be called 'Engineering', by analogy with 'Medicine', the name of the medical undergraduate program. It is intended to serve two separate functions in the marketplace:

1. to prepare graduates who will fulfil primarily operating and managerial functions in the workplace;
2. to furnish trainees, who, after apprenticeship in a specific industry, will become technical specialists on a par with engineers who have graduated from the traditional disciplinary programs.

These functions correspond to the way an undergraduate degree in medicine serves as a basis for subsequent training and careers, respectively in general practice and in the medical specialities.

In support of the first function, it is noted that many engineering jobs involve the management and operation of plants, factories and construction sites, activities which are practical and generally do not require knowledge of advanced engineering theory. On the other hand, because of the variety of the problems encountered in such positions, breadth of knowledge would be a definite asset. A typical example might be the manager of a soft-drinks bottling plant, which involves operation of mechanical as well as electrical machinery, electronic controls, and some knowledge of chemistry, microbiology, and environmental science. It appears that only a general practice engineering program would provide the breadth of knowledge required for this type of situation.

The lack of a disciplinary focus in a general practice program would be a distinct advantage, because it is recognized that students in a given engineering discipline usually dislike taking subjects in collateral disciplines, and as a result they do not benefit from such courses to the extent they should. Thus, to pursue the previous example, should the bottling plant manager be trained as a mechanical engineer, he or she may not be fully prepared, psychologically as well as technically, to cope with problems arising with the electrical machinery, with the electronics, or with problems of a microbiological, chemical or environmental nature. On the other hand, the graduates of a general practice program would have an unbiased interdisciplinary perspective which would better prepare them for this type of job.

The second proposed function for a general practice engineering program, which places its graduates on an equal footing with those of conventional programs even for technically demanding careers, is more controversial. To justify this proposition the training of medical specialists is invoked, in which graduates from undifferentiated undergraduate programs are successfully converted into specialists (psychiatrists, orthopedic surgeons, cardiologists, etc.) who are at least as differentiated as are mature practitioners in the various engineering disciplines. The key is that once the fundamentals of a discipline have been mastered in the classroom and the laboratory, more advanced knowledge is easily acquired under the mentorship of experienced engineers, or through self-learning, in the industrial apprenticeship setting. All neophyte engineers learn in this way when they begin their industrial career; the only difference foreseen between graduates of a general practice program and graduates of conventional programs at this stage is that because the two groups have different backgrounds there will be some instances in which one group will have a temporary advantage, and other instances in which the other group will have the advantage. It is however suggested that it is easier to acquire advanced knowledge of a specific area once the basics have been grasped than to learn a completely unknown subject, and that this favours the more broadly prepared graduates of general practice engineering programs.

CONCLUSIONS

The principal thrust of this paper is that the inexorable trend in industry toward ever greater complexity, sophistication and diversity is creating the need for an engineering graduate with a more broadly founded technical education than is currently being formed. The apparent paradox that as industry becomes more specialized it requires a less specialized graduate is easily explained: provided a sound foundation of fundamentals has been laid, specialized knowledge is more efficiently and more effectively acquired on the job, after graduation, than in the classroom before graduation. More efficiently because in the industrial setting specialized knowledge is acquired only as needed, and is not taught to those who will not require it, and more effectively because industry, not universities, has the greater expertise in industrial practices and knowledge, and also because the motivation to learn is greatest when the knowledge acquired can be put to immediate use.

There is no doubt that industry would welcome graduates of general practice engineering programs. A questionnaire survey of manufacturing industries in Ontario was recently conducted by the author's institution asking their opinion of a proposed general practice engineering program. A total of 377 responses was received, with the following results: 64% thought a more interdisciplinary education would in most cases *better* serve the needs of their industry; 81% believed that general practice engineering graduates would be as useful and effective as graduates from conventional engineering programs; 78% said they would seriously consider hiring general practice engineering graduates (with a further 9% giving a qualified 'yes'); and 83% recommended implementation of a general practice engineering program. The result of this survey is quite unambiguous: a strong demand exists in industry for engineering graduates who have received a very broad, multidisciplinary and non-specialized training.

Unfortunately it seems likely that, unlike industry, universities will not readily embrace this new direction. This is because faculty members prefer to teach the more specialized, research-related subjects, and also because they view the universities as being at the forefront of technological progress and having an obligation to pass advanced knowledge on to their students. While this may be appropriate at the graduate student level, the focus of the undergraduate programs should be on fundamentals and on broadly applicable skills, and specialization should be avoided as much as possible, as recommended by all of the recent reports on engineering education [3–6].

Regrettably, this advice is not being heeded by the universities, which are in many instances moving instead in the opposite direction of offering a smorgasbord of sub-speciality options within the traditional disciplines. The futility of this approach was exemplified by an employment survey of graduates of a specific year in a program option in biochemical engineering at the author's institution. Only one out of the 34 respondents was found to be employed in the biochemical industry, and two in related industries (food processing and waste water treatment). The rest were employed in the other industries, or were pursuing graduate studies (none in the biochemical engineering field). The result of this survey confirms the assertion in the report of the Canadian Academy of Engineering [6] that 'Experience has shown that, when highly specialized undergraduate programs and options were provided, only a minority of graduates pursued employment in their chosen specialities.'

The strategy of trying to mirror burgeoning diversity in industry by offering ever greater variety and specialization in undergraduate curricula is manifestly flawed, and in fairness to young students who have neither the knowledge nor the experience to judge the situation for themselves, should be reconsidered.

It is the author's expectation that pressure of competition will eventually persuade at least one university to offer a general practice engineering program, and that its success will then encourage others to follow.

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