Is Industrial Experience Necessary for Teaching Engineering?

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Abstract—The often made suggestion that all engineering faculty should have a substantial experience of working in industry is examined in detail. The numerous arguments given in support of the above suggestion are classified into five categories, depending on the shortcoming that the suggestion is meant to correct. These shortcomings are: lack of practice in real-life problem solving among newly graduated engineers; inadequacy in curriculum for broad, management, and specialized work; a bias towards research in faculty selection; inability of academics to develop creativity and other attributes needed in industrial work; and lack of a strong sense of professionalism among engineers. Each of the above sets of arguments is carefully analyzed to 1) isolate the source of the problem for which faculty industrial experience is being proposed as a solution, and 2) determine if, and how, that problem will be solved if the engineering faculty are indeed required to have industrial experience. The principal conclusion of this analysis is that some of the "problems" are the result of unrealistic expectations, and others are inherent in the nature of any limited-duration, university-based instruction. Imposing an industrial experience requirement for faculty would address few of these problems. Next, the case against imposing such a rigid requirement is examined. It is found first that there are several hidden costs, and some problems of definition and implementation in this proposed requirement. Finally, some suggested changes are summarized which will address the problems identified in the above analysis.

I. The Controversy

Most of the qualifications desirable in an engineering faculty are noncontroversial: the engineering educators must have a thorough competence in their subject matter, a flair for communicating technical ideas, a sensitivity towards students and their level of understanding, and other such attributes. But there has long been a debate on the necessity of substantial industrial experience among engineering faculty. A variety of opinions is held on this issue, ranging between two extreme positions: the first holds that a significant industrial experience (as represented by several years of industrial work) is essential, or even crucial, to proper engineering education, and cannot be substituted by research expertise, consulting, or summer work in industry, or other such professional activities. The second holds that such an experience is entirely irrelevant for engineering educators, or at least is not necessary, if at all desirable. A representative sample of views [1]–[9] on the two extremes of this issue is quoted in Table I.

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The purpose of this paper is to make a comprehensive study of this controversy. The historical reasons leading to the present status of industrial experience among U.S. Engineering faculty are briefly summarized in Section II. An attempt is made in Section III to compile an exhaustive list of the numerous arguments for requiring engineering faculty to have industrial experience that have appeared over the years in widely scattered sources in the literature, and each argument is then critically examined. Since any such proposal must be considered on a cost-versus-benefits basis, the potential costs and operational problems of imposing an industrial experience requirement on engineering faculty are examined in Section IV. The conclusions drawn from this study are contained in Section V.

II. The Historical Reasons

While there is little hard data available, it seems to be commonly accepted [10] that 1) a majority of the present engineering faculty in U.S. engineering colleges has little or no industrial work experience (there are, of course, notable exceptions), and 2) the average level of industrial experience among faculty has declined in recent decades. It would help to explore the reasons for this state of affairs before considering any changes in it.

The level of industrial experience among engineering faculty in the United States was never as high, nor as tightly regulated, as in some European countries [11], [12]. One of the important reasons for this appears to be the fact that from the beginning the engineering education in the United States was predominantly university based. The Morrill Act of 1862 (popularly known as the Land-Grant Act) provided federal aid to establish higher educational institutions that would emphasize advanced training in agriculture and the mechanical arts, and "to promote the liberal and practical education of the industrial classes in the several pursuits and professions of life." By contrast, in many countries, the training of engineers was carried out by "technological colleges," specially set up for this purpose. Still another system prevailed in England, where the engineers were qualified by certification rather than graduation, and the engineering institutions took the role of examining and certification agencies.

If the recent decades have witnessed a further reduction in the already low level of industrial experience among the engineering faculty, several factors may have been re-

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TABLE I
OPINIONS ON THE NEED OF AN ENGINEERING AND INDUSTRIAL EXPERIENCE FOR ENGINEERING FACULTY

PRO	CON
C. Perkins, President, National Academy of Engineering "While it is true that engineering student bodies are quite healty in numbers, very few students are really interested in the creative, innovative work that deals with high technology.... [A major influencing factors is that] the interest of the faculty in technical universities is changing very drastically with the appointment of young faculty members without the industrial experience or personal contact with the innovative process that characterized a faculty 20 years ago." [1]	H. Brooks, Dean, Division of Applied Sciences, Harvard University "In engineering (schools), we find increasing numbers of Ph.D.'s in physics and mathematics, and to a lesser extent, in biology and chemistry.... I feel this trend to be both inevitable and good with regard to balance.... A large part of the faculty of a modern engineering school must inevitably consist of people trained in, and working in, various relevant disciplines rather than of professional engineers. These disciplines may be traditional disciplines of either pure science or engineering science; the distinction is an artificial one." [6]
K. Corfield, Managing Director of STC in a report of National Economic Development Council "No new academic course in electrical or mechanical engineering should be approved unless it takes account of product design and development. Engineering faculties should not be permitted to take on new members unless they have industrial experience. And to promote links with commerce, all academic engineering staff at universities and colleges should have a spell in industry every five to ten years." [2]	M.E. van Valkenburg, Chairman of the Department of Electrical Engineering, Princeton University "The academic life differs considerably from life in industry. The normal procedure for the development of high caliber members of the faculty is to appoint such people at the time they receive the Ph.D. degree, and to place them in an environment in which they will develop good habits of teaching, research, and service to the academic community. Few of those who enter education after a period of time in industry develop these good habits." [7]
E. Walker, President Emeritus, Pennsylvania State University "We would be horrified if professors of surgery never had been surgeons. But we do have professors of engineering who have never been engineers. They graduated from college, went on to get an advanced degree, and took a short cut into teaching without ever having done any engineering.... These neophyte teachers are very good at analyzing, but the job of an engineer is synthesizing." [3]	H.G. Booker, Professor of Engineering and Applied Mathematics, Cornell University "I would not include.... any engineering department that still regarded its prime function as the professional training of students in empirical design.... in a university at all.... The professionally oriented undergraduate programs in engineering that are a feature of most well-established universities are a mistake.... The undergraduate education of potential leaders in engineering should not differ, so far as subject matter is concerned, from the undergraduate education of potential physicists." [8]
I. Feerst, Unsuccessful Candidate for IEEE presidency "All too often, the college professors who teach EEs have had no industrial experience.... This results in the unhealthy situation of having amateurs training amateurs.... What is so terrible about insisting that, as a prerequisite for accreditation, a substantial number of EE faculty have experience working in industry? I do not mean the one-day-a-week consulting done by the academics." [4]	D.C. Drucker, Dean of Engineering, University of Illinois at Urbana-Champaign "All engineers [should] have an introduction to research in the undergraduate and graduate years to operate at a high level of engineering practice.... Too many of the practicing engineers of World War II years.... found themselves embarrassingly incompetent to deal with the sophisticated engineering problems..... Over time, professional practice demands more and more fundamental knowledge.... it is the set of basic courses and concepts we label as engineering science which provide the essential preparation for the practice of engineering. Is it not remarkable that in these days of great discovery in the natural, social, and engineering sciences, there should be this growing pressure to turn back the clock to those good old days that never were when engineers didn't do research, or otherwise waste their time learning esoteric topics.... engineering students learned to be engineers from people who were engineers.... Our present research oriented professional schools of engineering are flexible and adaptable." [9]
J.K. Dillard, President of IEEE, and General Manager, Westinghouse "Less than half of the present engineering faculty has any significant experience in practice, and these are older faculty members soon to retire. How can the young research-oriented faculty teach *engineering practice in which it has no experience*? Do medical school professors who have never operated teach surgery? .... Schools should.... hire eminent design engineers and managers from industry to teach." [5]	F.E. Terman, Dean of Engineering, Stanford University "If you plan to be an educator, get into education immediately [upon graduation]. A close association with industry could be attained by frequent visits to industry and by working summers. A longer period in industry is not totally damaging but may disrupt the normal academic development." [7]

The affiliations and titles of individuals quoted are those from the time of the quoted statement, and are not necessarily their current positions.

sponsible. The two most important factors seem to be the following.

1) Change in the technology, and hence student needs: In the words of an engineer working in industry [13], "Until 1950's engineering students worked on applied engineering problems. But as technology grew more sophisticated, students had to spend more time learning theory." This, in turn, required faculty with more theoretical bent, who often had no first-hand industrial experience.

2) Change in the role of engineering colleges and faculty: According to Dean Andrew Schultz of the Cornell College of Engineering [14], "Prior to World War II, the typical engineering school was basically a teaching organization. The faculty generally had some industrial experience, and research was highly applied and limited in scope. The major change has been that most of our first-class engineering colleges are now also first-class research organizations. Their faculty are not merely teachers, but also researchers in the frontier areas of their specialties. This kind of orientation is desirable because it ensures the continued quality of the individual faculty member in terms of the subject which he teaches. The biggest change in the engineering curricula across the country came with the realization that all engineering students, regardless of their specialty, needed a solid foundation and a greater depth in mathematics, physics, and chemistry. . . . The education that a student now receives is far more general and fundamental, and it enables him to become far more flexible. . . ."

III. The Arguments for Requiring Industrial Experience

As a majority of the faculty at U.S. engineering schools does not presently have a substantial industrial experience, those who have proposed that such experience be required have had to carry the burden of justifying it. Although the various justifications given in support of the proposed requirements are highly interrelated, often incompletely stated, and rarely accompanied by a thorough analysis, a number of distinct arguments can nevertheless be identified. In the interest of an organized study they are classified here in five broad categories, taken up in the next five subsections.

The arguments are understandably based on certain traits of the present system of engineering education which are viewed by some as shortcomings. Each argument is therefore critically analyzed to determine if it is indeed based on a shortcoming caused by the lack of industrial experience among engineering faculty. One useful by-product of the analysis is that it reveals what changes might be desirable, either in addition to or in place of the imposition of a requirement on faculty, to alleviate the perceived shortcomings.

A. The Inadequate Practice Arguments

There are two principal components in the education and training of an engineering student: learning of basic principles, and practice in real-life problem solving. It is well recognized that the present engineering education in most U.S. universities emphasizes the former more than the latter [15], [16]. There are also in circulation many "horror stories" about the new graduate engineer who knew how to solve Maxwell's equation, but did not know how to repair a motor, or read an engineering drawing, or some other such skill in which the storyteller is proficient. Consequently, there has been a long-standing criticism that the education of engineers is too theoretical and abstract, and not sufficiently practical. This has sometimes been thought to result from the lack of industrial background in faculty, leading to the suggestion that the faculty should be required to have industrial experience.

This argument appears to be based on three components: 1) that the emphasis of present engineering teaching on principles is misplaced, 2) that there is a paucity of real-life problem solving in engineering colleges, and 3) that the problems solved by students are "academic" as a consequence of the faculty's lack of experience with practical, industrial problem solving. In the following, each of these components will be examined in depth.

Interestingly enough, the proper balance of theory and practice in engineering education has been a matter of concern for nearly a century [17], and although this concern has intensified since the Second World War, it was a source of criticism even when the engineering faculty had a significantly stronger industrial background. Moreover, this concern appears to be equally widespread in England, where the practicing engineers historically had a large role in the training of new engineers [18]. It appears unlikely that an ideal balance can ever be found to everyone's satisfaction, and a continuing evaluation and adaptation of the educational system may be the only possible course of action.

1) Misplaced Emphasis on Basic Principles: There is admittedly a stronger emphasis on abstract ideas and principles than on practice in current engineering education. A century ago the education of engineers consisted primarily of practical training which was gradually displaced by the basic principles. This shift in emphasis came about not because of the industrial inexperience among teachers but because it serves some useful purposes, such as the following.

a) Accomodating growth of knowledge: In a curriculum of fixed duration, the growth of knowledge in the field leads to overcrowding. In the resulting competition between basic principles and practical training and drill, there has been a conscious decision by educators to relegate the latter, rather than the former, to self-education. The emphasis on principles has allowed the length of educational programs to remain constant despite the explosive increase in the amount of useful technological information [19].

b) Slowing obsolescence: The essential distinction [19] between basic principles and problem solutions is that the principles have a wider domain of applicability, and a longer period of utility. There are numerous examples in engineering curricula [19] where the set of principles has stayed stable, while the problems solved with its help have evolved with technology. An emphasis on practice at the expense of principles will cause a more rapid obsolescence of the skills learned in college: the so called "cut-flower syndrome."

c) Organizing understanding: Basic principles serve as an organizing structure for a discipline, and allow a learner to develop a mental framework by which the solutions of individual problems can be placed in perspective, without which the discipline would appear to be a bag of tricks. As a result, learning is likely to be deeper and more efficient in principles-based mode than in problem-based mode [20].

d) Preparing for the more difficult: All of the technical knowledge needed by an engineer during a lifetime cannot be provided right at the start in the first degree course. Therefore, the most desirable goal of engineering education is to prepare an engineer to subsequently become responsible for his or her own education. Engineering education must be viewed only as a preface, and an engineer must remain willing to return to learning as and when needed. Experience has shown that students taught with a curriculum emphasizing the principles are in a better position to pick up the pragmatics later (either on their own or on the job), while the students prepared with a more applied curriculum find it harder to learn the basics.

Given the above advantages, one must accept the fact that an engineer trained with current curricula will require additional time after graduation before becoming a practitioner, and many employers recognize this fact [21]. The only danger of emphasis on principles may be that the educators may lose sight of the ultimate goal, namely the preparation of problem-oriented engineers. This risk can be minimized by having at least some faculty who are problem-oriented rather than discipline-oriented. If industrial experience promotes problem orientation, those with industrial experience will automatically be better represented in the pool of such candidates. It may also be necessary to ensure that such educators can maintain a problem orientation in a university environment, which is traditionally discipline-oriented.

2) Paucity of Training in Practice: The argument that current engineering education is entirely devoid of training in practice appears to be false. All curriculum design and accreditation guidelines include design-oriented curricular content. There are numerous existing intern, cooperative, summer, and on-campus work programs in which engineering students learn the practice and application of engineering principles under the supervision of faculty and industry. The on-campus research and development work conducted by the faculty under grants and contracts, both industrially sponsored and otherwise, also provides meaningful, practical engineering experience.

It would be more accurate to say that in most engineering curricula (with some notable exceptions), there is only a limited amount of training in practice. There are two reasons for this.

a) The depth versus breadth tradeoff: The first reason is related to the tradeoff between the breadth of technical material presently taught, and the depth of expertise that would come from increased practice. Since the future professional needs of all students are neither uniform nor can be anticipated in advance, it is felt that the purpose of training in practice can only be to exemplify the engineering process rather than to develop expertise in a few technical areas, so that the learning time is better spent in attaining a broader technical knowledge. Moreover, it is expected that the engineers will continue to have many more opportunities for practice after graduation, but few for broadening the base of technical knowledge.

b) Lack of facilities: The second reason for the presence of limited amount of practice in engineering education is related to facilities. Training in practice is senseless unless it employs state-of-the-art techniques currently used in industry. But such training requires up-to-date equipment in the university laboratory. To take a concrete example, if the engineering students are still measuring microwave impedance by the slotted-line method, it is not because the professors are ignorant of automatic network analyzers; such an automated system, which is commonplace in microwave industry, will consume the entire equipment budget for 10 years in many engineering departments. The university must, of necessity, run a low-cost operation. My informal survey of six engineering departments, graduating 50–200 engineers per year, showed that the annual laboratory equipment budget for supplies, repairs, replacements, and acquisitions averaged below $200 per student. To expect these engineers to have had first hand experience with fabricating LSI chips, computer-controlled robots, or laser communication equipment is therefore unrealistic. As a realistic indication of the cost of state-of-the-art training, consider the fact that the tuition fee for a commercial two-week training program is close to a half-year tuition fee at a private university [22]. If the universities have not been able to undertake expensive training, it may be because their customers (the students) are one of the economically poorest segments of the society, and because the benefits of education, to the student as well as the society, are only indirect.

If there is not enough training in practice, then the answer lies in providing more opportunities, motivation, and incentives for this activity, rather than in replacing the faculty by a different kind. It appears that bringing in an experienced engineer from industry to teach at the university would not solve the problem, but bringing in equipment and funds from the industry would help.

3) Academic Nature of Problems Solved: It is undoubtedly true that a majority of the problems solved by undergraduate students are academic in nature [23], meaning that, unlike the industrial problems, they do not involve a) ill-defined problem statements, b) real-life constraints, and c) multidisciplinary considerations. Student projects dealing with real-life problems are, of course, occasionally reported in the literature but these are newsworthy only because they are isolated cases or pilot programs, and are not the norm in the current, overall national picture of engineering education. The reasons for this appear to be different from the faculty's industrial inexperience, and include the following.

a) Realism of academic problems: In an earlier era, engineering was primarily an art, and the engineering knowledge was predominantly empirical. The growth of a hard scientific base for engineering practice has changed the situation. Vast segments of engineering are now based on principles, models, and formulas that actually work [24], [25]. The trend towards computer-aided design, the emphasis on basic principles in engineering curriculum, and the armies of Ph.D.'s in industrial research laboratories, are all a consequence of the new *modus operandi* of engineering. The analytical approach has not only been successful in design (for example, in synthesis by repeated analysis with perturbed parameter values), it is indispensible for such design tasks as optimization and sensitivity reduction. There are numerous engineering tasks such as microwave antenna design, that are crucially dependent on mathematical–scientific training that has been decried. To be sure there are also engineering tasks, such as pulling a low-defect silicon crystal from the melt, that rely primarily on experience and judgment. Some of these tasks are now increasingly assigned to computers by translating experience into algorithm. In short, the knowledge from physical sciences has driven engineering from being an art towards the status of a science.

b) Absence of in-house problems: The ultimate reason for the lack of truly "practical" problems in engineering curriculum is that the goals and roles of a university are very different from those of industry, because the university does not manufacture TV sets, generate and distribute electric power, or develop new airborne radars. Unlike a large industrial organization, a university has no in-house source of industry-like problems [26]. Even when a professor can identify such a problem, there are neither the resources (financial and manpower) nor the dedication (urgency and motivation) that an industrial organization will bring to bear on that problem. By necessity, the problems which the students use as a vehicle for learning can at best be only a simulation of the real life. (The only exceptions are research problems, which can be real because the universities themselves are engaged in the business of creating new knowledge). Such problems will always appear to be contrived or "academic" because they will be narrow in scope, fundamental in orientation, and free of major financial commitments and risk.

Increasing the level of industrial experience of faculty does not seem to address the above issues. Moreover, identifying a steady stream of meaningful and challenging real-life problems in sufficient numbers would require industrial cooperation more than industrial experience. It is indeed necessary for an engineer, who has been educated to account only for the scientific constraints, to learn that engineering work has many other considerations, such as economic, social, political, or commercial, and they may well dominate in the real-world. But experience shows that this is better learned from one's own experiences rather than from the teacher's work experience. It is unlikely that a different set of faculty will eliminate the need for a learning period early in one's professional career.

B. The Curricular Relevance Arguments

Many of the arguments for requiring industrial experience in engineering faculty arise from the dissatisfaction with existing engineering curricula, and the belief that an engineering faculty with substantial industrial experience would make the curricula more "relevant" to an industrial career. Among the many suggested deficiencies in engineering curricula, the following three are the most commonly mentioned.

1) The curriculum is too technical, and is suitable for a narrow specialist but not for an industrial career in which engineers perform a wide variety of functions [27].

2) The curriculum is too general and provides an inadequate training in the employer's specialties for the graduate's first job.

3) The curriculum does not meet the long-term needs of engineers because a large number of engineering graduates *eventually* end up in management careers while the engineering curriculum does not teach management [28], [29].

Numerous such complaints from engineers can be found in letters-to-the editor columns of engineering magazines, mentioning inadequate college preparation for industrial employment, and suggesting various alternative courses.

The need for such courses cannot be denied, because if engineers are asking for them, then by definition there exists a need. So why can't such "relevant" courses be simply added to the existing ones? Disregarding for the moment the basic disagreements (to be discussed below for each of the three areas of deficiency), there are two common operational difficulties in this. As the mutual contradiction of the first two deficiencies listed above already illustrates, no limited set of courses can anticipate the needs of all students. Second, with degree programs of restricted duration, and with the engineering curriculum already under pressure from expanding knowledge, the only way to accommodate new curricular material is to delete or deemphasize something from the present curriculum consisting of basic technical material. That this has not happened implies that such a substitution is widely believed by engineering faculty to be detrimental to the basic technical competence of engineering graduates.

1) Lack of Broad, General Education: Engineering is not a single profession; it is a multitude of professions rolled into one. There are research and development engineers, design engineers, system planning and analysis engineers, process engineers, operations engineers, facilities engineers, manufacturing and production engineers, quality-control engineers, testing and evaluation engineers, applications engineers, marketing and sales engineers, supervisory engineers, engineering managers, and, of course, engineering teachers. The diversity of tasks that engineers perform implies that the engineering colleges can only be expected to educate for technical competence, with the industry providing the subsequent training for the specific job function. If an engineer is to be educated for the entire range of job functions mentioned earlier, it follows that he or she must be educated for the one requiring the highest level of technical competence. This explains the emphasis on technical courses in the curriculum.

It is well-recognized that the national need for engineering manpower consists of two components [30]: a) a small number of engineers who have the highest technical competence, and b) a large number of engineers who are broadly trained and professionally educated. An educational system optimized to meet one of these needs will likely be suboptimal for the other, because the educational needs of the two groups are likely different [31]; for example, the education of the second group may involve less concern with the details of individual engineering devices, and more attention to the global view. In order that two separate educational routes be followed for the two groups, it will be necessary to presort the entering students for the two roles on some valid and fair basis. No such simple basis is available in a free nation.

A possible resolution of this dilemma would be the initiation of a greater variety of engineering programs. A wider latitude in the accreditation criteria for engineering programs may help encourage some more diversity.

2) Lack of Training in Employer's Specialty: A narrow specialization during undergraduate years is undesirable for a number of reasons.

a) Low versatility: In the initial years of industrial employment, an engineer is likely to be called upon to solve a broad range of problems, requiring a correspondingly board training. While many engineering positions do require specialized knowledge, a student usually does not know in advance which position he will be taking up after graduation. Even if he did know the specialization needed after graduation, it would be unwise for him to spend his undergraduate training time in learning something of value to a particular employer, because the benefit of such a training would accrue to the employer rather than to the individual.

b) Rapid obsolescence: Perhaps the most important pitfall of specialized training is the risk of obsolescence. To quote Gardner [32], "The future is necessarily hazardous for the individual who trains himself to do a specific job, receives an advanced degree for that line of work and believes that society owes him a living doing it. If technological innovations reduce the demand for his specialty, he has nowhere to go. On the other hand, if he is broadly trained in the fundamental principles and knows he may have to apply these principles in varying contexts over the years, he is in a position to survive the ups and downs of the job market."

c) Low cost effectiveness: Even if specialized training was necessary, there are major operational problems in the university environment. Education in a university is cost effective only because of the large class size. If a given specialty is required by a very small number of students (e.g., three per year at one college), it might be cheaper to provide on-the-job training to them in that area. Specialized training requires equipment and instructors trained in the specialty, which can be expensive to maintain in a college. In addition, specialties come and go, so the personnel and equipment are highly susceptible to obsolescence. In the absence of funds and mechanism for preventing this obsolescence, only the basic principles, which have longer shelf-life, can be emphasized in engineering curriculum.

How then should the needs of specialized training be met? There already exist numerous short-course offerings on current, specialized, and advanced topics, offered by university extension programs as well as entrepreneurs. Consultants, both academic and others, are available to conduct custom-made training programs. Finally, unless employers undertake the full responsibility of retraining an engineer when their needs change, they must be prepared to train an engineer in their own specialty rather than ask the engineer to have learned it in college.

3) Lack of Management Training: This criticism is a case of unrealistically high expectation. A first degree course can hardly be expected to prepare a student for two careers, as a technically competent engineer as well as a manager. The option of obtaining two degrees (or additional courses) is of course open to all those who are qualified and are willing to spend the additional time in school. To require all engineers to prepare for two careers simultaneously seems unnecessarily restrictive. In any case, the initial employment after graduation is almost always based on an engineer's technical competence, and the engineering education should be judged by its ability to impart this competence. Those who change careers subsequently should be prepared to spend the additional effort at that time.

Even if it is decided that engineering students should be taught business management, that teaching would best be done by management teachers, just as engineering students now learn mathematics from mathematicians and humanities from humanists. The need for industrially experienced faculty is not clear. Finally, management training may further reinforce the attitude, which some find diminutive [27], that technical and engineering work is only a stepping-stone to something better, and not a lifelong profession. Indeed, if physicians are to be emulated in this regard, there need not be any business training in engineering at all, because the normal career progression of a physician does not include management [33].

C. The Research Bias Arguments

Many of the arguments on the necessary qualifications for engineering educators touch on the subject of research emphasis on the campus, and the low priority given to teaching abilities and practical experience in the selection and retention of faculty. Furthermore, the university's expectation of continued, significant research involvement prevents many industrially experienced individuals from becoming engineering educators. Since the selection criteria and expectations are, to some degree, determined by the already existing faculty, it is easy to be led to the conclusion that an industrially experienced faculty would change the emphasis.

A discussion of the reasons for emphasis on research in faculty selection will be lengthy and distractive here. In short, the primary reason for the emphasis is that a university is not, and must never become, a teaching shop [34]. If this is accepted, the research emphasis is easier to understand. What must be conceded is that research has sometimes been defined too narrowly on campus, and a diversity of research types should be welcome. A secondary reason for research emphasis is the large amount of external (mostly governmental) funding available to engineering faculty for research, and the absence of a comparable support for educational activities or engineering practice. This situation is indicative of the societal expectations, and the engineering faculty can hardly be blamed for meeting them.

A detailed defense of the research involvement on campus will not be given here, except to point out some of the educational benefits of campus research. Research is the principal means through which engineering faculty remain technologically current. (This, however, does not imply that other means of maintaining technical competence do not exist.) Therefore, while "teaching" means efforts devoted to teaching present students, "research" can be viewed as effort devoted to teaching the future generation of students. Research is also perhaps the only source of real-life problems in a university environment, as mentioned earlier. Finally, research orientation is indispensable if the engineering college is to maintain any involvement in graduate education.

Suggestions are often made [35], [36] that the universities should employ teachers who have industrial experience and a flair for teaching, but who are currently excluded, either because they do not have Ph.D. degrees, or due to the university emphasis on research and grant activity. There is some merit in this suggestion. The principal reason for its nonacceptance appears to be the tenure system of educational institutions. There is understandable hesitation in bringing aboard those teachers who would likely have lower probability of fighting professional obsolescence and maintaining technical currency over the years.

D. *The Creativity and Productivity Arguments*

The education of engineers should concern itself not only with learning in the cognitive domain (e.g., technical knowledge and skills), but also with training in the affective domain, i.e., with the development of such personal attributes as work habits, attitudes, interests, outlook, and motivation. It is sometimes suggested that engineering educators who have not worked in industry will not have an adequate awareness and appreciation of the personal attributes required for productive industrial work. Furthermore, industrial work provides the faculty an opportunity to develop the proper attributes themselves. This is desirable because teachers often serve as role models for their students, and because they can be more effective at inculcating in their students the attributes which they themselves possess.

In particular, the work attitude and the creativity of new graduates are the two principal examples of neglected attributes mentioned in most of the arguments for requiring engineering faculty to have industrial experience. Developing proper attitude towards industrial work, and nurturing the students' creativity, are admittedly worthwhile goals; they are examined in the following only to question the changes that may be expected if the faculty is required to have industrial experience.

1) Inattention to the Development of Proper Attitudes: One's work attitudes are determined by the entire range of experiences from early school years to postgraduation employment, and the influence of the college faculty may well have been overestimated. As an example, the low number of engineering graduates pursuing doctoral degree programs in the last decade, and the consequent shortage of faculty members, despite strong encouragement and role modeling from the faculty, would seem to imply that faculty play a small part in determining the attitudes of their students towards professional work.

A second weakness in the argument relates to the presumed conditions under which the proper attitudes are developed by the faculty and the students. If the faculty can learn the desirable "industrial" attitudes only by spending some time in industry, how will students learn these same attributes from the faculty within the university setting, prior to entering industry? It appears that if the faculty can develop the right attributes by spending some time in industry early in their career, the newly graduated engineers, who will spend their entire career in industry, can do the same. The disadvantage in the present system, wherein the proper attitudes are acquired by an engineer on making the transition from university to industry [21], is not apparent.

It is also not apparent that the attitudes of engineers in industry and university are vastly different. If the optimal attributes for success in industry and university are indeed so different, another problem arises: if no change is made in academia other than bringing in industrially experienced faculty, how will the faculty with the "industrial" attributes thrive, or even survive, in academic setting.

2) Stifling of Inventiveness: The industrial inexperience of engineering faculty is sometimes said to cause a loss of engineering creativity and inventiveness in the new graduates because the "scientific methods" taught in universities are believed to be different, or even antithetical, to the "engineering methods" of value in industry [37]. The central theme of this argument is that the university teachers are proficient in scientific research rather than in industrial problem solving or inventing, and there is a basic difference between the two kinds of activities. The research is based on the scientific method, which requires that each step follow logically from an earlier, established step, and therefore, results in advancements which are incremental in size and narrow in scope. By contrast, inventing requires that an unusual or seemingly illogical connection be made, beyond what is recognized to be the normal domain of a problem, and thus leads to breakthroughs [38]. As a result, an emphasis on rigorous scientific and analytical methods in engineering education can stifle inventiveness and creativity [39]. Presumably, an industrial experience early in the career would make a permanent change in the problem solving style of faculty, and this difference would come from solving industrial problems, and from observing, and associating with, inventors found in industry, rather than academic researchers.

Admittedly, art is learned from an artist, and not from art historians, critics, curators, or analysts. Whether it is also true that creative engineering problem solving is better learned from inventors rather than from engineering researchers, and whether the teaching of a rigorous, logical approach to problem solving actually suppress creativity, is not known. The following observations are, however, relevant: a) A certain percentage of faculty members are creative, just as a percentage of engineers in industry are, and the two percentages are probably very similar; b) the mere requiring of an industrial work experience for faculty will hardly ensure that the engineering teachers are creative, let alone whether they can teach creativity; c) it seems unlikely that a clear understanding of the fundamentals of a subject, which is the goal of much of the engineering curriculum, can harm an individual's inventive potential; d) there is no report of any evidence, even anecdotal, to indicate that the creativity is higher among engineers who learned a subject from an industrially experienced teacher, or graduated from a college where most faculty have such experience; and e) engineering creativity has, at best, only a second-order relationship with the nation's current sagging industrial production and balance-of-trade problems, which are primarily dependent on a large number of other factors, and are not indicators of educational deficiencies [27], [40].

E. The Professionalism Arguments

In recent years, and especially since the employment crunch of early 1970's, many engineers have wanted to "professionalize" engineering, with the goal of improving their salaries, social status, prestige, clout or job security. The physicians (and sometimes lawyers) have been cited as illustrative examples of "professionals," with their economic and social rewards serving as goals for engineers. Emulation of physicians brings up the arguments like "only-surgeons-can-train-surgeons," [3], and the teaching of engineers by those never employed in industry has been criticized. There are two defects in this line of reasoning. The first is the assumption that an engineering teacher is not an engineer, and the second is the incorrect comparison of engineering with surgery.

1) Definition of Professionalization: The word "professionalize" has not been defined unambiguously, and it has been taken to mean a number of things [41]–[45]: to register as a Professional Engineer (P.E.), to control entry into the profession, to practice engineering in an ethical and competent manner, to be responsible for one's design or product, to practice engineering as a consultant, and to have the primary allegiance to a professional association rather than to an employer. Serious attempts [46] at definition show that a profession is characterized by a large number of factors, none of which prescribe the employment history of its educators. That engineering educators are not professional engineers can hardly be argued, when they have the same educational background as many engineers in industry, compete and collaborate with industrial researchers on the same research problems and on similar lines of investigation, work as consultants or summer employees for industrial establishments, and often (usually in the first few years of the academic career), leave academia to join industry (indeed are sometimes sought after).

2) Analogy with Physicians: The superficial analogy between surgeons and engineers is invalid due to some major differences between them. A surgeon is much closer to the craftsmen like plumbers, while engineers are very different from craftsmen [47]. The work of surgeons and plumbers requires a knowledge of empirically established rules, procedures, and conventions, rather than the mathematically formulated principles and fundamental physical laws which form the basis of engineering. The mode of acquisition of this professional knowledge is therefore also different. In both surgery and plumbing, apprenticeship is the primary mode of learning, so that the training must be on-the-job. In engineering, problem solving skills can be practiced on models because the models work so well. The analogy between medical professions and engineering may have been valid in an earlier era, when engineering was also predominantly an empirical art. It is conceivable that someday the advancements in biological sciences will similarly affect the medical profession. Finally, the training of surgeons and plumbers, being practice-based, is narrow: an eye surgeon cannot be an orthopedic surgeon, or an air conditioning plumber cannot be a sewage plumber, without another apprenticeship. By contrast, mathematicians, chemists, and others have often solved engineering problems without explicit engineering training.

There are two other reasons why engineers and engineering education are not analogous to physicians and medical education. First, unlike practicing engineers, practicing physicians do not innovate. Much of the medical advancement is being carried out by individuals who are trained as biochemists or physiologists. The situation is somewhat analogous to prewar engineering, when physicists contributed heavily to the development of new engineering devices. Second, medical schools have traditionally operated (indeed are expected to operate) hospitals which provide health-care services in competition with those provided by practicing physicians. By contrast, engineering colleges do not operate manufacturing plants, public utilities, or even product development shops, which may compete with industry, and are not expected to compete. In the few cases where they did, typically as defense contractors, the industrial arms separated from the universities for one reason or another. Perhaps the different expectations stem from the fact that hospitals are viewed as public service, while the industry is viewed as profit-motivated, and therefore, not in harmony with the ideals of a university.

IV. The Case Against Requiring Industrial Experience

The arguments against establishing a requirement of industrial experience for engineering teachers can be grouped into the following three categories.

1) The Costs: Several potential "costs" of the proposed requirement of a period of industrial experience for all engineering educators can be identified and are as follows.

a) Decreased attractiveness of teaching career: The rigid requirement of industrial experience will undoubtedly decrease the attractiveness of the teaching profession for some individuals. In particular, it may exclude from the engineering educators a certain class of individuals who are best described as "scholars," and who may be dissuaded by the entry requirement from pursing an academic career. This will be detrimental to engineering education, because such individuals perform a very useful service. Many such individuals can be identified in academia, and an examination of their work over the years indicates that they have contributed greatly to the systematization, coordination, and cumulation of engineering knowledge, thus increasing the efficiency of the instructional process.

b) Higher cost and/or teaching load: A substantial salary differential between industry and academia is a well-established fact. For example, the annual IEEE salary surveys [48] show that of all the job classifications included in the survey, such as manager, sales engineers, R & D engineers etc., the one with the lowest salaries for equivalent degree and experience levels is one of educators. If industrial experience is made mandatory for faculty, the universities would be forced to bring in engineers from industry at a considerably higher salary. However, in a system with limited resources, limited by the state legislatures for public universities and by the size of endowment for private universities, there would have to be fewer professors. As a corresponding reduction in the number of students would further reduce the available funds, a steady-state will be reached in which there are even larger classrooms and heavier teaching loads than is now the case. This is hardly conducive to improving the skills of a graduating engineer.

c) Risk of faculty stratification: If a minimum industrial experience requirement is indeed mandated, for example by denying degree accreditation without it, there is a real danger that a two-tier faculty would develop at the engineering schools of the nation. One set of faculty would be responsible for the accredited undergraduate instruction, while another would carry on the graduate education and research activities, which do not require accreditation. The undergraduate faculty would have the industrial experience, larger teaching loads, little time for research and professional renewal, and lesser motivation to infuse new ideas into the curriculum. The graduate faculty would have the time, facilities, student assistance, and funding to engage in research, but their lack of industrial experience will restrict them from teaching undergraduates. This will reinforce the stereotyped image of an engineer as a tradesman, and the engineering profession would lose its attractiveness to some superior students. If this scenario seems unrealistic, consider the situation at universities which presently offer both engineering and technology programs.

2) The Definitions: A second part of the case against requiring an industrial experience for engineering educators is based on the lack of clear definitions and goals. As pointed out earlier, the engineers perform a wide variety of tasks in industry, from R & D to sales work. Therefore, the requirement that engineering educators have "industrial experience" is rather vague. It is defined on the basis of who the employer is (university versus nonuniversity), rather than on what the individual did or learned during employment. Does "industrial" employment include working for the government? What about employment in an industry-owned college (such as GMI) or with a university-owned nonprofit corporation? Should employment in all nonprofit organizations be excluded even if the work in some is indistinguishable from that of profit-making organizations? Must industrial experience be gained after receiving the graduate degrees, or is earlier experience prior to entering the graduate school acceptable? Is industrial experience once in lifetime sufficient, or should there be periodic industrial exposure? Do sabbatical leaves, consulting work, and summer work constitute a genuine industrial experience for faculty [16]?

These questions arise because the purpose of requiring the industrial experience is not clearly stated. For example, is the industrial experience valuable for the technical currency and awareness of the state of the art it presumably bestows, or is it needed for the inculcation of some attitudes which can only, and always, be developed by a period of industrial employment? Perhaps the need is to develop a more objective description of qualifications that would be desirable in engineering educators.

3) Problems of Implementation: A third part of the case against an industrial experience requirement stems from the problems of implementing such a rule without making any other changes in the universities, such as in the level of financial support, faculty selection and reward system, and the extent of industrial cooperation. The problems mentioned below are not unsurmountable, and their mention does not imply a defeatist attitude; however, their existence must be recognized in any serious consideration.

It might appear that the level of industrial experience of engineering faculty can be enhanced simply by preferentially employing those with an appropriate experience. This, however, does not take into account the realities of academia [49], [50]. The present difficulty of academic recruiting is evidenced by the large number of vacant teaching positions in U.S. engineering colleges, variously estimated to be around several thousand [51]. But even a decade ago, when the candidates were plentiful and teaching jobs were scarce, the universities were unable to lure faculty away from industry. The university salary levels are substantially lower (say 70–80 percent) of the industrial salaries [51], the promotion and retention criteria in universities place premium on the publishability (and hence novelty) rather than engineering utility of research work; and there are definite advantages to having entered the research arena early in one's career. Finally, there is the problem of how the faculty member will keep his/her industrial experience and contacts current, especially with the facilities available in the university.

The "updating" arrangement, wherein the faculty go to work in industry periodically [52], has its own difficulties. Perhaps the most important deterrent to this arrangement is the reward system in academia which encourages the continuity of research and student supervision on campus that would be interrupted. But even if this was to change, there is no indication of an industrial willingness to accept these temporary employees, as the cost effectiveness of short-term employees is low. Since the benefits derived by industry are mostly indirect, and not all industries can share this burden in proportion to their use of engineering graduates, the "faculty training programs" in industry must necessarily rely at least partly on the goodwill and altruistic nature of corporations. Such arrangements lack permanence, and are quickly cutoff in a pinch. There are a number of other problems, such as the propriatory nature of many company activities, the perception of faculty as to the challenging nature of their task in industry, the difficulty of matching industrial openings with faculty interests, etc.

In view of these problems, suggestions are often made to secure industrially experienced teachers by engaging industrially employed engineers as short-term teachers. In a typical adjunct appointment, an engineer may work full-time in industry, teach a couple of evenings a week on campus, have almost no other involvement on campus, and receive a compensation equal to perhaps 6 or 7 percent of his annual salary in industry. Such adjunct or visiting faculty will rarely create a change in the nature of engineering education on campus. Moreover, the selected individuals resemble an average faculty more than they resemble an industrial engineer in their professional attributes, and often they teach specialized courses for a few graduate students rather than a typical undergraduate course. But even if that were to change, it is not clear that there would be an adequate supply of teachers from industry. Companies have a great need for their own outstanding engineers, and the time for which an engineer can be released does not always match academic timetables.

Conclusions

Like any other human activity, engineering education can be improved, and none of the above discussions are intended to imply that the current mode of engineering education and faculty selection is perfect. Indeed, the proposal for requiring industrial experience for all engineering faculty positions has come up exactly because many individuals perceive certain shortcomings in the present system of engineering education. Some of these shortcomings admittedly exist, and the willingness of these individuals to contribute their time and effort to a discussion of the shortcomings must be constructively utilized. It will be unfortunate if this opportunity for affecting a change is lost because the attention is drawn away from the real problems to mere symptoms or incidental issues. The requiring of industrial experience for all engineering faculty is an action which will misdirect the attention away from the real source of the problems, will incur costs without benefits, and will give a false sense of having solved the problems.

An in-depth analysis of the arguments given in favor of requiring an industrial experience has shown that the various forms of dissatisfaction from present engineering education can be traced back to two fundamental sources: the nature of educational institutions and the enlargement of the knowledge base needed for engineering. The two sources of problems, and some thoughts on what can be done about them, are summarized in the following.

1) The nature of educational institutions: Engineering education will always be constrained by some characteristics which are inherent in a university, unless a completely different form of institution is envisaged for carrying out the task of engineering education, a suggestion sometimes made on other grounds as well [53], [54]. These characteristics include the lack of an in-house source of real-life engineering problems, the lack of resources to match the industrial state-of-the-art in the laboratory, the need to prepare engineers for a vast variety of careers not known in advance for each individual, the unavailability of means for professional updating of the faculty except through research, and the need to maintain curricular uniformity for a large number of students in order to be cost effective. Only some of these limitations can be removed by stepping-up the level of support to universities in terms of funds, equipment donations, and faculty opportunities for professional work.

2) Enlargement of the knowledge base: The rapid expansion of the engineering knowledge, along with a static duration available for engineering education, is the second principal source of problems. It leads to crowding in the curriculum, and forces the exclusion of practice, drill, general education, specialization, and state of the art in favor of the abstractions, principles, and fundamentals. One method of dealing with it is to emphasize, both to engineers and to engineering employers, that education is not a one-shot process. Continuing education is indispensable, especially for engineering education in times of rapid technological advancement, and some further education is necessary when there is a significant change in career, such as entry into management. A second suggested method is to increase the length of engineering degree programs. This suggestion has an important hidden cost, namely a loss of the present flexibility, wherein an engineering graduate with the first (B.S.) degree has the choice of proceeding for a M.S. degree (at the same time possibly changing the school, or moving to a different part of the country), or a degree in business administration, or obtaining some work experience before returning for further education, or working in a job function in which further education is not needed, or even entirely changing the career plans.

How then should those with industrial experience participate in the training of new engineers, and the engineers in training benefit from a wider range of experiences? The two options that least suffer from the mentioned disadvantages are the following.

1) Joint university-industry appointments for faculty: A significant fraction of engineering faculty can be appointed jointly between university and industry [55], with each appointment being close to half-time to guard against token commitments. The willingness of both the university and industry to accept an employee with only a partial commitment would be evidence of the individual's high desirability. Many problems will have to be resolved in such appointments, related to the potential for conflict of interest, the award of academic tenure, the enlargement of academic reward criteria to encompass industrial work, the flexibility of schedules to meet work overloads for either employer, and career development paths for those beginning such appointments early in their career.

2) Requirement of internship in industry for graduation: Perhaps the most direct method of avoiding the limitations of engineering education due to the nonindustrial nature of a university is to relegate a part of the education of an engineer to industry. In a number of countries [11], the requirements for the award of an engineering degree include a period of apprenticeship in industry by the candidate. If the practice component of the preparation for an engineering career is presently too weak in the U.S., it can be supplemented by an industrial training, either on the job, or in an apprenticeship capacity. Similar suggestions have been made by other authors based on other reasons [56], [57]. Although this, in effect, increases the length of the degree program, the added time is spent in employment rather than in further schooling. The industrial environment is particularly suited for this form of training, where the student will meet both real problems with real constraints, as well as problem-solving engineers who can serve as role models.

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