Needs and Possibilities for Engineering Education: One Industrial/Academic Perspective

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Abstract

This paper reports a personal assessment of the readiness of new B.S. level engineering graduates to practice engineering immediately upon graduation. This assessment when reinforced by significant prior work motivates a systemic analysis of the U.S. Engineering Education System. The analysis is framed to address the implementation potential of ideas for how educators might efficiently teach undergraduate engineers "that engineering is more than differential equations". The concepts which seem best from this analysis are combinations of aggressive intern opportunities combined with courses (starting in the freshman year) that emphasize the creative engineering process. These activities may be containable in the 4 year program but the analysis also suggests that extension of engineering education to 3 or more years beyond the B.S. would improve the possibility of reaching key educational goals including teaching adequate math and science fundamentals as well as engineering knowledge, process and creativity. Such radical change will be difficult and slow to occur (if at all) in this complex system. Moreover, this system is understandingly resistant to change because of significant perceptions of outstanding achievement. The driving force for change that may be strong enough to overcome these barriers is prospective students' falling perceptions of engineering education as a preferred option.

I. Introduction

This paper originated with a question I was often asked during my career at Ford Motor Company: namely, how well prepared are current engineering graduates to do engineering when you hire them? In this paper, I attempt to answer this by reporting an assessment of new engineers versus attributes exhibited by successful practicing engineers. The result of the analysis is generally consistent with previous work [1] that identifies weaknesses of new engineers in understanding and capability relative to engineering practice essentials. Not surprisingly, such findings have been noted by many and help drive many reform activities [2]. Perhaps the most important such reforms revolve around Engineering Criteria 2000 and the

ABET accreditation-connected initiatives. This paper takes the shortfalls identified and extracts a preliminary problem statement and then examines ideas for addressing the shortfalls. The examination strives to take a systemic but *necessarily* not deep view in order to assess the implementation potential of the various engineering education reform concepts.

The analysis of engineering education from observation of new graduates is given in Section II. A preliminary problem statement is also given in this section. Section III introduces the systemic framework used in the analysis of potential changes envisioned for engineering education. The basic elements of the engineering education system are also introduced in section III. Section IV briefly outlines some aspects of the history of engineering education in the U.S. This history highlights events that the author believes are important relative to the problem statement and the assessment of implementation potential of reform suggestions and activities. The current state of the engineering education system in terms of the elements of the framework in Section III is given in Section V. Section VI contains a preliminary broad assessment of implementation potential of some types of activities underway (or proposed) for addressing the shortfalls identified in Section II. An overall view of what this analysis suggests is given in Section VII which also briefly examines a broader problem statement than that given in Section II. In doing so, I conclude that radical change is possible for the system.

II. Assessment of New Engineers

The first part of this assessment is against a series of attributes that I developed during the 1980's and used initially in mentoring sessions with new engineers at Ford Motor Company. The list is shown in Table I and covers activities that successful engineers did well as part of the fundamental engineering design process. This list was later used (in the 1990's) in presentations I gave to larger groups of newly hired engineers. In all cases, the new engineers were asked to do a critical self-assessment against these attributes and then review their perceptions with a senior engineer advisor for accuracy and for suggestions for actions that could result in significant improvement in the shortfall areas identified. The right hand column in Table I shows a personal assessment (in normal grade fashion) of my perceived average of typical newly hired B.S. level engineers from 4 year programs at U.S. "top 20 engineering schools". I noted to incoming engineers that most had received A's and B's in their courses at top engineering schools but would have to continue to learn aggressively to approach the A level practicing engineer. For my purposes here, the generally low level of these assessments is one statement of the problem being studied.

Table I. An engineer should be able to…

	Rating
• Determine quickly how things work	C-
• Determine what customers want	D
• Create a concept	C-
• Use abstractions/math models to improve a concept	C
• Build or create a prototype version	D
• Quantitatively and robustly test a prototype to improve concept and to predict effectiveness	D
• Determine whether customer value and enterprise value are aligned (business sense)	D-
• Communicate all of the above to various audiences	C-
• Much of this requires "domain-specific knowledge" and experience	D-
• Several require systems thinking and statistical thinking	D
• All require teamwork, leadership, and societal awareness	D

The second assessment tool first attempted for this paper is to use the list of attributes developed by Boeing over the years [3]. Table II shows these criteria with "grades" assessed by me again for B.S. Level engineers from 4 year programs at U.S. "top 20 engineering schools". Again the grades are relatively low. These low grades are personal, may reflect a slowly evolving engineering domain and therefore are somewhat arbitrary. However, the comparison to a successful practicing engineer as an A is a difficult standard for the average new engineer to meet.

Table II. Boeing list of "Desired Attributes of an Engineer"

	Rating
• A good understanding of engineering science fundamentals	C
o Mathematics (including statistics)	C
o Physical and life sciences	C
o Information technology (far more than "computer literacy")	B
• A good understanding of design and manufacturing processes (i.e. understands engineering)	D
• A multi-disciplinary, systems perspective	D
• A basic understanding of the context in which engineering is practiced	D
o Economics (including business practice)	D

Table II. Boeing list of "Desired Attributes of an Engineer" (continued)	Rating
o History	D
o The environment	C
o Customer and societal needs	D
• Good communication skills	C-
o Written	C
o Oral	C
o Graphic	D
o Listening	C
• High ethical standards	?
• An ability to think both critically and creatively—independently and cooperatively	D
• Curiosity and a desire to learn for life	C
• A profound understanding of the importance of teamwork.	D

A previous study by Todd et. al. [1] solicited feedback from industry to find perceptions of weaknesses in engineering graduates. A *few* of the weaknesses they reported are:

- No understanding of manufacturing processes
- Lack of design capability or creativity
- No knowledge of value engineering
- Lack of appreciation for variation
- Poor perception of overall engineering process
- Narrow view of engineering and related disciplines
- Weak communication skills
- Little skill or experience working in teams

This study [1] does not report the numbers of individuals or actual response numbers in the feedback but the findings are roughly consistent with my personal assessment above.

A more detailed and deeply documented study of perceptions of industrial expectations of new engineers was reported by Lang et. al. [4]. They examined 172 attributes (related to 11 EC2000 [5] outcome categories) and note that this can be useful for curriculum developers. I will not recount their study here except to note that they did not try to assess new graduates but went much more in depth in statistically valid ways to assess "wants". One of their key results is that in 6 of the

11 categories, the highest ranked attributes—in terms of desirability for new graduates according to their industry responders—"describe competencies not addressed in traditional engineering education". Thus, this quantitative study tends to generally support the qualitative results previously described in this section.

The "problem statement" derived from the needs studies and rough assessments in this section clearly involve perceptions about lack of engineering practice knowledge and skills. Many of the studies also point to the post WWII emphasis on engineering-science as—at least partly—causing this shortfall. Most people do not want a reduction in understanding of math and science but argue for a better integration of the science and engineering process/creativity education. A short version of a problem statement might be:

> *How do engineering educators **efficiently** teach undergraduate engineers that engineering is more than differential equations and that using technology to help society involves more than engineering?*

The bolded adverb is an attempt to include in the problem statement the constraint of fitting these learning objectives into the engineering curriculum (time and other resources) without undue impact on other aspects of the education process.

III. Framework for Analysis

In this section, a framework for assessing the implementation potential of education reform ideas that have been or can be formulated to address the problem identified in section II is outlined. The emphasis is on attempting to identify ideas which can in fact be expected to be implemented widely with reasonable support. The first part of the framework is simply the recognition that ideas with high implementation potential are those whose driving forces sufficiently exceed the resisting forces. The driving and resisting forces are dependent upon perceptions of the total value of the concept by the various people involved in the proposed change. Thus, the implementation potential is positively related to the perceived ability of the concept to solve the stated problem (driving force) and also how well it is perceived to address the other needs (potential resisting forces) of stakeholders who have significant power in the system in question. The power involves the ability of a stakeholder to promote (or resist) the suggested changes. If a given idea is strongly opposed by a ***key*** and powerful stakeholder, it does not have high implementation potential even with strong support from other stakeholders.

The engineering education system is shown schematically in Figure 1 highlighting two aspects. The top of the figure shows some key processes in the Engineering Education System. The processes shown are the education process, the research process and the fund generation process for the education institutions in the system. It should be noted that not all education institutions in the system participate in research but for those who do, there is close interaction between

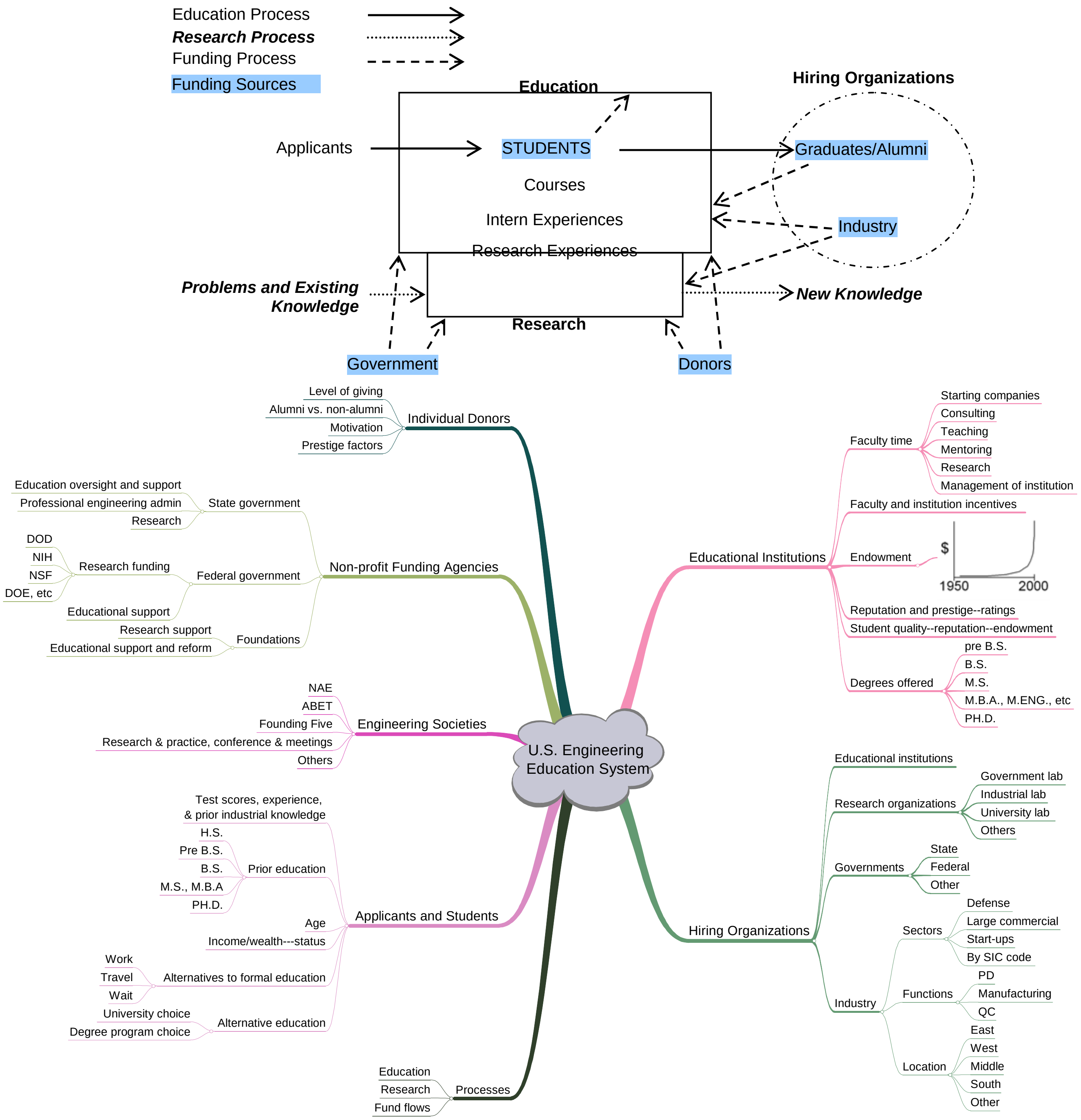


Figure 1: The Engineering Education System

education and research (particularly for PhD's). The bottom of the Figure highlights all of the stakeholders and some of the structure in the overall system (starting from reference [2]). The interactions in neither part of the Figure are fully shown as the representations would be then too complex to visually comprehend. For example, new knowledge (the fundamental result of the research process) can be of direct interest to students, alumni, industry and other stakeholders in the process diagram in the top of Figure 1. Similarly many elements of the system shown in the bottom part of the figure have interrelationships of importance that are not shown. As important next steps, we must establish the current state of this system and the history which gave rise to the current state if we are to have an understanding that is adequate to assess implementation potential.

IV. A Brief History of U.S. Engineering Education

This section contains a broad but not deep analysis of the subject and cannot be represented as exhaustive scholarship. Nonetheless, it significantly extends the time-frame usually referenced in engineering education reform discussion and doing so raises some issues relevant to our problem statement. This historical summary is also MIT-centric which at least partly reflects the authors' current affiliation but some could argue that MIT has had significant impact on U.S. engineering education and thus should receive emphasis.

The first engineering school in the U.S. was the U. S. Military Academy at West Point founded in 1802 and was in response to needs expressed by Washington, Adams and others during the revolutionary war [6]. West Point graduates became important in non-military engineering in the following decades but a pressing need for civil engineers caused the second engineering school, RPI, to be formed in 1824. The rise of mechanics (or Mechanical engineering) was not accepted by existing schools or engineering societies [7] and was accommodated educationally as the industrial revolution proceeded by the land-grant or Morill Act in 1862. Over seventy "land grant" colleges, as they came to be known, were established under the original Morrill Act; a second act in 1890 extended the land grant provisions to the sixteen southern states [8, 9].

The importance of the land grant colleges on U. S. engineering education cannot be exaggerated. These schools still form the essential core of U.S. engineering education. William Rogers, by convincing the Massachusetts legislature to grant 1/3 of that state's Morrill monies to his then fifteen year crusade, was finally able to start MIT because of the Morrill act [10]. With these new institutions, new engineering fields were much more quickly integrated into university education as continuing technology development identified the need for such fields. A persisting negative fallout is that fulfilling the now clear need for more interdisciplinary education of various types remains challenging partly because these original disciplines have become hardened into the education system.

Several important innovations affecting the education of engineers occurred about 100 years ago. The first of these is described in the University of Cincinnati engineering school website [11]:

> *Welcome to the University of Cincinnati College of Engineering, the home of cooperative education. It was here in 1906 that Herman Schneider became Dean of the College and implemented his co-op plan "joining theory and practice, linking education and industry through knowledge and experience" in the Departments of Chemical, Mechanical, and Electrical Engineering. In the near century since its inception, the co-op program has thrived and has been replicated at least in part by more than one thousand institutions of higher education throughout the world.*

This innovation is thus still important today despite the fact that most leading schools did *not* adopt the innovation. It should be noted that from my experience with newly graduating engineers, "co-op" graduates grade substantially higher on the many attributes discussed in Section II which "are not addressed in traditional engineering education". Because of the basic nature of the programs and their intent shown in the quote above, such results are not surprising.

President Charles Eliot of Harvard and the industrialist and philanthropist Andrew Carnegie were instrumental in numerous education innovations in the period being discussed. They joined forces in 1904 to convince the MIT president (Pritchitt) and the MIT "Corporation" (board) to have MIT join Harvard as the core of Harvard's engineering/technical graduate school. Despite strong MIT alumni and faculty objections the merger/takeover proceeded until the Massachusetts Supreme Judicial Court stopped it because part of the plan was to sell MIT land in Boston and move near Harvard. The SJC found that MIT could not sell the land because of constraints in the Land-grant charter for the school [10, 12].

A few years later, Harvard found another use for the land Carnegie had donated to Harvard in order to facilitate the movement of MIT to a location near Harvard. This alternative use was for another education innovation of the 100 year-ago period and is described at [13] in the following fashion:

> *Founded in 1908, Harvard Business School was initially conceived as a "delicate experiment" in the new field of professional management training. Harvard was the first university to require a college degree for admission to its business program.*

Thus, the failure to establish the first professional engineering school enabled success in forming the first professional business school. By the 1950's and beyond, many engineers were expected to obtain necessary understanding of business by obtaining an MBA and this combination was one method for obtaining some key skills noted as missing in engineering education in Section II. By the time of the author's own MBA experience in the late 70's, the decoupling of technical and business knowledge was so severe that this combination was questioned by many as to its real value to engineering practice. In addition, I believe this event plays some role in a tendency to sharply separate engineering and management in some engineering-based U.S. Corporations.

In addition to concerns about the lack of professional status that may accrue to a field where 4 year graduates may practice, this period also saw concern about the necessity of "broadening" engineering graduates through requirement of the study of humanities. In my own experience, the "Carnegie plan" was much discussed as an essential part of education at Carnegie Institute of Technology (now Carnegie-Mellon University) in the late 1950's. An emphasis on problem-solving as a key engineering skill (independent of domain knowledge) and emphasis on broadening humanities were the two intellectual pillars of "The Plan".

A major issue in our problem discussion and its consideration by many is the relationship between engineering education and science and its evolution during the post-WWII period. Through reading many accounts, one might conclude that the imposition of science into engineering education did not start until about 1950. There were no doubt significant changes over many schools at this time. However, at the founding of the earliest engineering schools [6, 7], they were considered special because of the recognition that engineers needed a deep fundamental understanding of math and science to practice well. Indeed, innovative engineering schools [10, 14] were apparently the first to teach scientific topics well 150 years ago. In summary, I believe a good case can be made that a continual process of increasing scientific content and depth in engineering education occurred over the years as scientific knowledge advanced symbiotically with engineering accomplishments. Despite or because of this continuing process, the increase in science education at the expense of practice has also been controversial over the last 150 years [7, 15]. It is significant that as Carnegie, Eliot and Pritchitt were attempting to extend engineering education, a fierce debate was underway ("shop vs. school") concerning the already too great separation of engineering education from practice. Important engineers argued for experience before schooling and for reduction in requirements such as mathematics [7].

Along with the science/practice controversy, the accusation of lack of sufficiently deep and excellent science as part of the U. S. engineering education process has also been relatively constant over this period. The comparison to engineering education in France and Germany and the importance of people educated in Europe such as Timoshenko and Von Karman in changing U.S. engineering education is noteworthy evidence [15]. At MIT, a significant increment of science-infusion started in 1930 with the appointment of the outsider and accomplished physicist—Karl Taylor Compton—as president [16]. He and the man he named vice-president and dean of engineering- Vannevar Bush—supported a significant increase in focus on Ph.D education and an embedded research mission to assure continuous science infusion into engineering education. The events of WWII did again demonstrate the importance of scientific knowledge to engineers and this along with the NSF and

DOD funding for research that grew greatly in the 50's substantially fortified this infusion of science into engineering education. At MIT, the role of Harold Hazen as engineering dean is important as he personally felt that the success of the MIT "rad lab" physicists in developing important technology relative to the (not unsuccessful) MIT servo lab he headed during the war was due to superior education of the physicists [17]. At Stanford, Frederick Terman who worked at MIT's rad lab during the war apparently had similar motivations behind his drive to reform Stanford engineering education [18].

V. Current State of the Engineering Education System

One of the most difficult parts of discussing implementation potential of reform concepts for the U.S. Engineering Education System is to assess the relative effectiveness of its current overall contribution to society. There are various points of view and associated metrics that can give counter-indications, for example: 1. Global economic development; 2. National economic development and competitiveness ; 3. Environmental degradation and species extinctions; 4. Health and life expectancy; 5. "inequitable" economic distributions; 6. Reputation and prestige of Educational Institutions nationally and internationally; 7. National and regional entrepreneurial activities; 8. Opportunities and lack of opportunities for talented people to rise greatly in social standing; 9. perceptions of value of the graduates to hiring organizations. In none of these can engineering or engineering education be looked at independently of other factors such as market, legal, political structures and other parts of the broader education system that the engineering education system is embedded in. It would be easy to give credit or blame to engineering education (or specific institutions) that actually have little impact. Despite these caveats, the immense accomplishments of engineering globally and nationally over the past 200 years [19] and the international admiration for at least parts of U.S. engineering education means that the *general driving force for substantial change is relatively small*. In addition, the major problems of modern life (pollution, economic inequity, etc) are generally attributed to business and governmental institutions and not at all to educational institutions. Thus, we are understandably dealing with a *system that has good reasons to resist change.*

Issues for which some hold the educational system accountable include the lack of understanding of engineering and technology of generally educated people (a serious problem given the importance of engineering and technology) and the shortfalls in practice skills of new engineering graduates discussed in Section II. We now turn to discussion of the various stakeholders introduced in Figure 1 relative to their power and relative influence on change in the engineering education system.

One of the *two* most important elements of the education system are the *educational institutions*. They are important because they have substantial power to make or not make changes. They are also directly affected by any changes made. As implied in

Figure 1, there are a great variety of types of institutions involved in engineering education from community colleges to major research institutions and all of these institutions (within and between types) cooperate and compete. At the community college end of this spectrum, funding and assured roles are less secure. Thus, these organizations work to develop close customer-driven relationships with hiring organizations and tend to innovate more easily and have positive influence on changes relative to the problem statement in Section II.

At the major research institution end of the spectrum, there is again cooperation and competition among institutions for students, research funds and donors. These institutions have "virtuous circles" among high incoming student quality, attraction of "desirable" faculty, ratings of the institution, donations, prestige and endowments. Endowments have increased so rapidly over my lifetime that institutions with inflation-adjusted endowments a factor of 10 greater than anyone had not many years before are now represented as woefully under endowed. The tendency to resist change discussed above is particularly understandable at this end of the Educational Institution spectrum. The faculties who also internally cooperate and compete are significantly powerful in these institutions. Faculty, particularly when in agreement, can cause or stop any curriculum change. I know of no surveys but it appears that majorities of faculty who can both teach and do research well prefer institutions with great freedom to travel widely and do research. The prestige of international recognition that comes from a successful research career is apparently and understandably preferred by most over limitations imposed by *increased teaching loads*. It is important to recognize that there is no available spare time for faculty involved in research, education and other activities of value to the university despite typical non-university perceptions.

The endowments have grown largely from donations from various sources including alumni and other wealthy individuals. This study has not attempted to quantitatively detail the sources of the donations and the motivations of the donors. However, it is clear that association with prestige institutions is important to donors as are alumni relationships. It is also appears that donations focus as much on enabling further research accomplishments as on furthering or reforming education. Indeed, it is rational that donors would not usually want to be associated with lack of excellence or to donate in order to solve controversial problems. On the other hand, it is easy to imagine that alumni donors would oppose discipline consolidation of "their" departments and might be joined by self-interested faculty to make such reform impossible for the university. One could be accused of cynicism but it is appears that donors have not recently caused any education reform to occur that would not have occurred without their involvement.

A third stakeholder and one often called on for more involvement are the hiring organizations- particularly industry. My assessment is that industry has only little power and has alternative ways to address the problems in Section II that they will generally favor over a battle they would rather not fight. The reasons for the low power assessment is the impossibility of using their theoretically strongest potential power- hiring boycotts. The following factors preclude coordinated and powerful boycotts: 1. different perceptions between different industry sectors; 2. different needs such as research and engineering within an industrial sector; 3. differences among technical disciplines as to the importance of attributes needed to be successful; for example, differences in practicing analysts and practicing design engineers is noted in reference[4]; 4. alumni relationships create loyalty to different schools independent of other variables; 5. desire to associate with prestige and rated schools independent of other factors. In general, industrial firms are motivated to want to hire the graduates of the leading universities if for no other reason than incoming student quality and only lose interest when such graduates do not accept their best offers. The firms are thus oriented to partner with not battle these universities in particular. The alternative actions industry and firms can and do undertake to address the problems in Section II include hiring from other firms, hiring co-ops, hiring only at the masters level, in-house education, cooperative continuing education with partner universities and many others including combinations of items in this list.

Further stakeholders who will try to address shortfalls include government bodies and foundations. These institutions have had significant past influence and continue to play important roles. NSF in particular has been much more active in engineering education and has aggressive and helpful activities underway [20]. However, as with donors these institutions are at least as interested in other aspects of the "university system" as in engineering education. NSF's education activities [20] support science, engineering and research jointly and not separately. Thus, they do not focus on the shortfalls discussed in Section II.

The engineering societies including NAE have also played a continuing role in engineering education and this role has been very active in the past decade [21,22]. The societies have a particularly strong influence on the Engineering Education System through ABET which administrates the accreditation of engineering schools. ABET/EC 2000 [5] is a remarkable vehicle that is designed to drive change in the system. This development is most important because of its flexibility. Unlike previous criteria, which were rigidly defined, EC2000 encourage each institution to become outcome-oriented and define its own role and adapt an appropriate curriculum for this role. The well-known "outcomes" 3 a-k directly focus on the issues discussed in Section II.

There has been much significant work since the criteria were first identified in 1995. This includes significant documentation of different experiences, e.g. [23] and broader exchange mechanisms for sharing best practices are part of The NSF [20] and Carnegie Foundation efforts [24]. Recently, Felder and Brent have published a very useful paper [25] identifying extensive prior research that relates to each of the

3 a-k outcome categories. They also present a useful glossary and details about how to develop overall objectives, learning objectives and course design methods in response to the criteria. In addition to the significant energy devoted to these efforts, attention is being paid to how much progress they cause to occur. Prados [2] has noted the key role of assessors and industry in this process and Splitt [26] has discussed important "cultural" factors. Thus, the efforts of the Engineering Societies are well aligned with the goal of alleviating the problems discussed in Section II. An *important positive factor* in the engineering education system (easily overlooked because of the discord that it engenders) is the interaction of the societies (and thus practitioners) with education through ABET.

The other stakeholders (in addition to the education institutions) that I believe have significant power in the system under question are the *student*s. Education Institutions compete strongly for prospective students of high quality as the key input resource. Thus, the prospective student has *power through choice* and this choice involves not only which university but which field of study to pursue. The apparent reduction in appeal in engineering education over the past decades is thus likely to be the *most significant driver for change* in the system. Again in this scoping study, details of motivations for student choices are not studied. However, from my interactions with students and prospective students (even the best of those with a strong inclination to do engineering), it appears that the high workload, early forced choice, narrowness of undergraduate engineering education and the sometimes confusing professional status of the field are important hindrances. If this guess has any general validity, it has important implications for the direction of engineering education reform.

VI. Implications for Engineering Education Reform Concepts

The preceding discussion indicates a highly interactive system with high esteem but also with a serious problem concerning prospective students. The interactions are numerous and strong within the system which increases the difficulty of implementing change. Some interactive aspects that we have only alluded to are important elements of solving the broad issue of effective engineering practice. For example, the rise of masters degrees that have both technical and business education components (e.g. MIT's LFM and SDM programs) is an important factor in producing engineers with superior total skills including leadership. Indeed, the apparent increase of engineering masters degrees is itself an important element of reform. Other key interactions that influence reform implementation include the close linking of research and education at the leading institutions and the importance of research success on prestige, endowments, ratings and incoming student quality.

The discussion in Section V indicates quite a lot of satisfaction with the U.S. engineering education system despite the dissatisfactions indicated in Section II.

This does not make such shortfalls less real but does increase the difficulty of implementing reforms to address the issues. For example, changes that would strongly decouple education and research do not seem to be feasible as they would be opposed by major funding sources as well as by most faculties at the leading U. S. engineering schools. As a specific example of reform, MIT has appointed a few "Professors of the Practice" (e.g. the author) and this helps address the issues raised in Section II. Since learning to teach well also requires some experience, widespread implementation of this model may be problematic. Moreover, if such Practice Professors oppose research activities, their value in the institutions is reduced. It is likely that such factors explain why EC criteria requiring software to be taught by engineers with practice experience have been eliminated in the next edition [5]. In addition, the issue of balancing incentives between education and research for faculty is tempered by a concern with the possibility of long-term faculty becoming significantly behind the knowledge-front for engineering practice and research.

The most serious problem facing the engineering education system is the falling interest in this system by prospective students. While this *might* primarily reflect weaknesses in other parts of the education system (secondary or primary schools), it is the factor that is most threatening and therefore most likely to drive change. Before discussing this issue further, I want to consider the implementation potential of reforms for increasing the overall value of engineering graduates to hiring organizations.

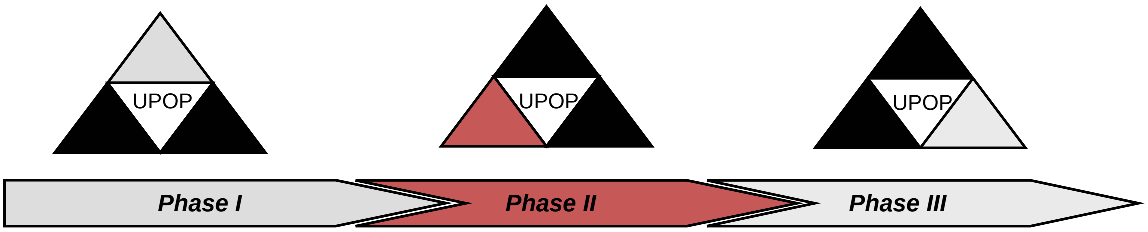
There have been numerous suggestions for addressing the problem statement in Section II. I will not try to address many of these but only discuss a few of what I consider to be the most important. Courses where the students gain knowledge of the engineering process such as integrated capstone courses [1], freshmen engineering process and content courses [27, 28, 29], and engineering problem solving approaches [30, 31] are essential to address the problem. These experiences all help address a lack of design or synthesis-oriented courses in the standard curriculum. They have been shown to be effective and my personal experiences within MIT's Mechanical Engineering Department convince me of the value to the student. However, such courses often depend for their effectiveness on strong mentoring of students by faculty. Thus, they require significant faculty resources and will be difficult to support over the long-term unless well-integrated into the total curriculum.

Another specific approach for addressing the problem statement of section II is now presented. There is no intention to argue that such an approach is optimal. For example it relies on successful partnerships with industry to be effective. MIT has started two "accelerated intern programs" (FASIP for freshmen and UPOP for sophomores) that might help address the issues raised in Section II *efficiently*. I will describe UPOP here further as I have been part of the instruction team for the first two sessions (2002 and 2003). The name is a deliberate derivative of a well-known

MIT program- UROP or the Undergraduate *Research* Opportunity Program- that has existed since the late 60's. UROP basically involves giving students laboratory and other research opportunities involving credit and deepening involvement. UROP has been favorably received by students and is generally considered an important education innovation. UPOP is the Undergraduate *Practice* Opportunity Program and involves significant preparation for and post facto learning about a summer intern assignment that MIT tries to find each student. The top part of Figure 2 shows the basic structure of the program which begins with the students (sophomores only) taking an intensive 1 week "course" during IAP (MIT's Independent Activity Period held in January). The one week course is modeled after a corporate training seminar and introduces the students in an active way to aspects of engineering practice.

The content for the 2002 version is shown in the bottom part of Figure 2 and clearly addresses many of the issues in Section II. The "course" has been given to 80 students at a time with two sessions of 80 each in 2003. The students work in a 9 person team and each team has a dedicated mentor (an experienced engineer) for the entire week. The students receive feedback about teamwork, presentations and leadership as well as engage in "practice experiences" during the week. The three phases give students a chance to learn, to apply the learning in a real practice situation (the internship) and to learn more from the experience from post-facto review. It is too early to fully assess this concept but it appeals to me because much of what I learned about engineering practice during my undergraduate education was due to my good fortune to have internships (summer jobs with some structure) after both my sophomore and junior years. I believe I may have learned significantly more with a program like UPOP consciously enhancing the experience. The program appeals to students and addresses the problem well as it integrates a practice experience into the university education process. Thus, I believe it may have high implementation potential. Attracting sufficient experienced engineers and faculty time as well as receiving industrial support for the internships are important issues that need to be solved in order to allow such programs to have broad impact.

In closing this section, I want to note that the ratings in section II of ability to apply math and science principles to engineering is also not satisfactory for the 4 year engineering graduates. Thus, I consider the rise in masters degrees and combined masters degrees as extremely important reforms. Such programs may have high implementation potential since they allow for efficient use of resources when existing graduate courses (sometimes research oriented) can be utilized in these programs. Implementation of "combined"masters may be limited by the "divide" that now exists between engineering and business schools in many universities. I believe *significant reform attention should be on increasing the quality and breadth of masters level graduates*. I also think that the ASCE recommendation and strategies [32] that the masters degree be considered necessary for practice is a



UPOP IAP Workshop	***UPOP Summer Practice Experience***	***UPOP Reflective Learning Experience***
3 Units P/F	1 Unit P/F	Part of Phase II 1 Unit P/F
• Student completes intensive IAP workshop • Topics include: leadership, strategy, customer requirements in product development, making presentations, leadership among others	• Student completes 10-12 week internship • Students participate in supervisor/peer conference calls • Students complete online Engineering Practice Journal	• Student participates in roundtable discussions with fellow UPOP students and TA's from the UPOP IAP Course • Students complete reflective exit interview

Monday 1/28/02	**Tuesday 1/29/02**	**Wednesday 1/30/02**	**Thursday 1/31/02**	**Friday 2/01/02**
• Intros & Expectations (10:05-10:30) • Student Intros (10:30-10:50) • What is Engineering? (10:50-11:35)	***Daily Briefing*** • Carson Racing: Data Analysis (10:15-12pm)	***Daily Briefing*** • Answerphone: Specifications (10:05-12pm)	***Daily Briefing*** • Customer Requirements & Communication : Presentations (10:15-12:15)	***Daily Briefing*** • Leadership (10:15-1pm)
Lunch 11:45-12:30	***Lunch 12-1pm*** ***Room 26-110***	***Lunch 12-12:35*** ***Room 26-110***	***Lunch Speaker 12:25-1:45:*** *Desh Deshpande, co-founder Sycamore Networks*	***Lunch 1-2pm*** ***Room 26-110***
• "Beer" Game: System Dynamics (12:30-2:15)	• Internet Bust: Presentations (1-2:40pm)	• Robust Engineering Design (12:35-2:30pm)	• Strategy (1:55-4:45)	• Self- & Course Assessment (2-2:30) • Next Steps (2:30-3pm)
Break	***Break***	***Break***	***Break***	
• Beer Game Discussion (2:30-4:30)	• Customer Requirements (3-4:15pm) • Team Dynamics (4:15-4:45pm)	• Nanobioinfo: Interpersonal Conflicts (2:45- 4:35pm) • Customer Requirements (4:35-5pm) • Homework is daily assessment & feedback		Wrap-up/ Celebration
Daily Assessment & Feedback	***Daily Assessment & Feedback***		***Daily Assessment & Feedback***	

Figure 2. MIT's Undergraduate Practice Opportunities Program

very important reform step making more feasible the achievement of *both* practice and math/science fundamental skills in practicing engineers.

VII. Concluding Remarks

The reform underway in engineering education involves many effective innovations that will help address the shortfalls identified in Section II. How well this works will depend on the "fit" of the reforms within the engineering education system. However, the analysis in Section V indicates that a broader problem statement may be appropriate. Such a broader problem statement would also recognize the importance of whether the changes are sufficient to change the basic view of engineering education by incoming students. The programs discussed in Section VI have all been well-received by the students who enjoy the course work and content very much. It is not clear however that such changes will be reflected in the desirability of engineering education to prospective students. Indeed, it seems unlikely that such relatively small changes will affect broad viewpoints that are likely the determinants of perceptions of incoming students. It is my opinion that solving this problem will require a more radical change.

The nature of the radical change is highly uncertain and probably not discernable until after it occurs [33]. It is nonetheless possible to speculate about it and I will do so starting from an important and provocative article that Williams has recently written addressing this issue [34]. She concludes that students are forcing a reintegration of undergraduate engineering education with general University education. She also concludes (as the title of her article implies) that the engineering profession is disintegrating which implies that engineers will come from multiple, diverse and unpredictable educational experiences.

The engineering profession has "always" had various education pathways into practice in addition to the "normal" 4 year engineering bachelor's degree. These include science plus practice, science plus masters in engineering plus practice, cooperative education, various other practice mixed with education paths [35]; indeed even today there are outstanding engineers without 4 years of post-secondary education. Thus, fragmentation is not new and should continue.

An important possible addition to the William's scenario is to resurrect (recognizing that history cannot be reversed) the attempt by Eliot, Carnegie and Pritchard of a century ago to establish the profession of engineering practice as requiring significant graduate education. It seems obvious to me that to do much of modern engineering practice well requires more education than that required to do law well. Thus 4 years after the B.S. seems appropriate for at least an important part of the profession beyond those going into research. Although a start has been made by the ASCE recommendation of requiring a master's degree or equivalent for licensing and practice [32], there has been modest innovation in education institutions relative to such changes. Such professional engineering programs could also be accompanied by moderate consolidation of the engineering disciplines and should take advantage of the design, synthesis and creativity oriented reforms mentioned in Section VI.

There are numerous significant issues involved in such radical change but I will only discuss two here. The manner in which these programs would interact with existing research-oriented Ph.D programs and MBA programs is one issue. Some of the developments relative to EC2000 would fit well within professional programs (e.g., team design projects and integrated Intern opportunities). A second important issue involves making very revolutionary changes to undergraduate education. However, ABET's new flexibility alleviates the possible accreditation issue and increasing the creative part of early engineering education is positive from the point of view of this paper. Moreover, the revolutionary changes in undergraduate education could be designed to simultaneously allow much wider insertion of interesting courses in engineering and technology [36] into other undergraduate curricula. Such reintegration of engineering into the core of the university *along with its further development as a profession* is my solution for the problem of the declining appeal of engineering to prospective students. Reversing this decline is, in my opinion, the most important challenge we face in engineering education.

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