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Influencing Student Learning: An Industry Perspective*

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Much has been written over the past several decades about the need for reform in engineering education and the elements of what such reform might encompass (e.g. enhanced curricula with a stronger emphasis on design, improved pedagogical methods). Most of this literature has been written from an academic rather than industry or employer perspective, with a focus on faculty and curricular issues. Relatively little has been presented from a student perspective. The issue of what factors influence students in their choice of pursuing a career in engineering or how they might be educated and retained in engineering education programs has not been adequately addressed. The purpose of this paper is to discuss some of the steps we within the broader technical community (in industry, government and academe) can and should take to assure an adequate future supply of well prepared engineering graduates for the full range of employers who have need for such talent. Although much has been accomplished in the past decade to enhance engineering education, we, as both educators and practitioners, have much to do to cooperatively create a strong and vivid vision of our future, and ensure the proper development of a future generation of engineers with the skills and motivation to meet society's needs in our ever-evolving enterprise.

Keywords: engineering manpower; engineering career, professional skills; industry perspective.

INTRODUCTION

THE PRESENT PAPER is a continuation of a lengthening series [1–21] on engineering education and related issues of importance from an (aerospace) industry perspective. An important point to be noted, however, is that, while the focus of these writings has been on 'aerospace' engineering, a company like Boeing, in common with most others in our industry, employs many more electrical, mechanical, manufacturing and computer-related engineering graduates than it does those with explicit *aerospace* engineering degrees. In this sense, the subsequent text relates to industry interests in engineering education enhancement and reform in a broad sense.

The development of the technical workforce needed to support our industry in the future, and academe's role in it, continues to be the central concern of this paper. There are a variety of recruiting, hiring and professional development issues that need to be addressed in order to support various industry priorities. Some of these issues are new and unique to our times (e.g. the 'globalization' of many of our major companies, the need to effectively deal with an international terrorist threat that now extends to our own shores), and others (e.g. the general volatility in employment, often poor utilization of available talent) have plagued industry for decades. Many of these issues have been discussed in our earlier papers [1–13]. One topic that requires further elaboration, however, is the fundamental question of what we need to do to attract and prepare a future generation of engineers as seen from the *student's perspective*. Most discussions of industry needs and engineering education enhancement have dealt with these issues from an educator's (faculty) or practitioner's perspective. Less often considered is the question of 'what's in it for me' for a student uncertain about his or her future in a profession which remains poorly understood in the minds of too many in the general (lay) population. Fig. 1 is a general summary of factors that influence student learning and career decisions, some of which will be considered in more detail in later sections of this paper.

In order to create a realistic message for our young people, it is important for all of us to give thought to a suite of strongly interrelated questions. These include:

- How many engineers will we actually need in the foreseeable future? Nationally? Globally?
- What skills and knowledge should these engineers possess to maximize their potential for continuing employability—both at an entry level, and over the longer terms of their careers?
- What challenges and opportunities can we offer a future generation to ensure that we attract an adequate, continuous supply of the high-quality talent we will need to transform dreams into reality and satisfy societal needs?
- What can we—individually and collectively—do about these issues?

As a matter of both personal and professional interest, the author has been wrestling with these and related questions for a long time. Many of us

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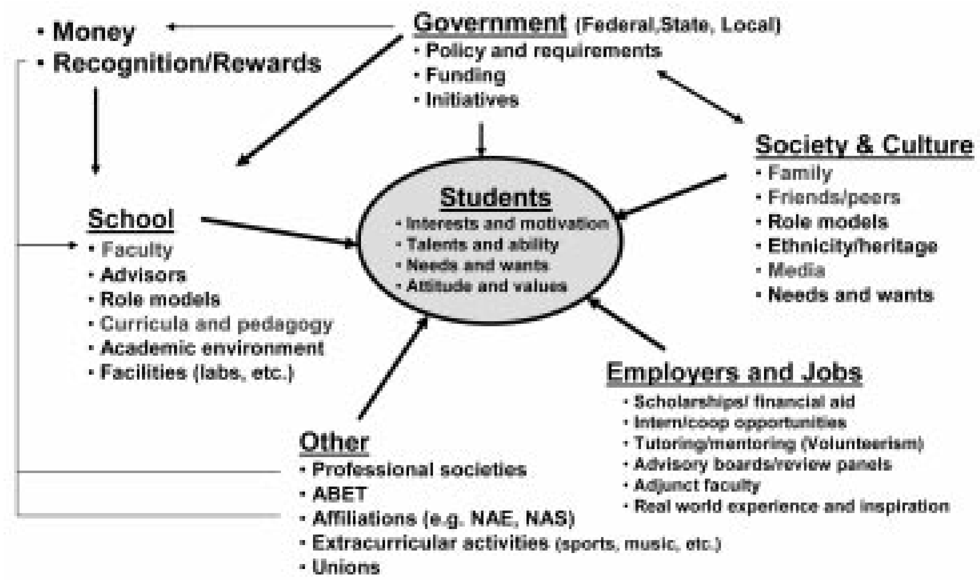


Fig. 1. Factors influencing student learning and career choices.

have also been involved in efforts to 'do something' about the conclusions we have drawn over the past twenty years. Some accomplishments can be claimed in what have been largely team and community-wide efforts. One example has been the formulation and adoption in late 1996 of the 'outcome-based' ABET Engineering Criteria 2000 as the first major change in the preceding forty years in the way engineering programs in this country are accredited. In part, this was an effort to better align engineering education programs with industry needs, and to allow faculty to more creatively experiment with curricula and pedagogical methods. What direct influence this change in accreditation may have had on students and their perceptions of our profession and the educations they receive is seldom discussed, however.

HOW MANY ENGINEERS *DO* WE NEED (AND WHAT WILL THEY *DO*)?

Particularly vexing has been the problem of estimating the number of engineers and scientists our enterprise will need in the future. Such projections are required for strategic planning in all our constituent business organizations, and the institutions that support them—particularly academe. In some way we must seek to balance overall supply with demand throughout the *entire system* that is our overall technical community, as well as at the level of individual companies, agencies or institutional units where most attention tends to focus. In principle, this issue should be easy enough to address, but in practice it is not, beginning with the simple problem of defining a common time horizon for what may be meant by 'strategic' among the diverse constituencies that make up the suite of employers of our graduates. Is it two, five, ten or forty years?

Chasing these requirements is somewhat analogous to trying to guess the performance of the stock market. Looked at over the short term—say two to five years—there is so much volatility in most industry sectors that projections can only be made on the basis of estimates of the market for products and services to be delivered and the work this entails. In this model, an implicit assumption is usually made that, since the nature of the work to be done will remain similar to what was done in the recent past, the required mix of skills will remain roughly as they have been. The problem then becomes one of estimating the number of new employees required as the difference between voluntary attrition and the imperatives of 'remaining competitive' via productivity increases and process improvements which can allow overall headcount reductions—and thus cost savings, possibly increased by global outsourcing.

Summing the numbers from across our industry, including its vast supporting infrastructure and network of users and suppliers, then gives an estimate of our future needs for new graduates to replenish the aging population of talent available—modified by the prospect [12] of an increasing capability to automate many tasks that historically have provided employment for large fractions of our technical workforces. Any task which has become well understood and routine can, in principle, be better and much more cheaply done by machine, especially if it is dangerous, dirty or merely tediously boring.

The above concerns aside, if we assume a healthy continuing growth in our national and global economy, with product development opportunities along more-or-less traditional lines, one might reasonably conclude that due to various compensatory factors the *number* of engineers and scientists we will need in the foreseeable future is roughly the same as those we currently

Fig. 2. The Boeing list of 'desired attributes'.

have, although the required skill mix may change significantly [4, 7, 8, 11, 13]. The only remaining question is that of where the work will be done, and by whom. As we move toward further globalization, however, this mildly optimistic estimate suggests a somewhat grim prospect for employment for US engineering graduates unless they have skills and expertise that are in high demand (e.g. system integrators and architects [8, 11]) or are relatively invulnerable to off-shore outsourcing (e.g. involving services that require significant direct interpersonal interaction with customers or suppliers).

Whatever projections one may make about future workforce needs, we in aerospace have now endured an extended period in which sincere commitments, such as the one made to his employees by the late, great Clarence L. ('Kelly') Johnson of the legendary Lockheed 'Skunkworks', can only appear nostalgically quaint: 'I owe you a challenging, worthwhile job, providing stable employment, fair pay, a chance to advance, (and) I owe you good management and sound projects to work on.' How many of us have longed for a return to such simpler times? Alas, we must live in the world we have, and the future, in any detail, remains unknowable to us.

While the estimation process outlined above is time-honored, in the end it proves to be frustrating in that it seldom leads to even approximately accurate projections beyond a time horizon of about six months to a year (even within a single company or agency, let alone across our own industry alone). Given that the time-scale for the development of our people is very much longer than that for the usual product development cycles that frame most industry thinking, one must still attempt to make some sort of projections in order to assure that our future workforce needs can be met at any foreseeable time.

Faced with such situations, one may usefully approach the problem from a 'futurist's perspective' [13] and examine underlying 'first principles' that can provide useful guidance. One successful example of this approach was its use in the construction, circa 1993–1994 of the Boeing list of 'Desired Attributes of an Engineer' (Fig. 2). The original purpose of creating this list was to establish a basis for an on-going dialogue with academe at a time when much legitimate criticism was leveled at various potential employers for a seeming propensity for 'changing their minds all the time' and sending often contradictory messages to schools regarding 'what industry needs'. Rather than provide schools with continually changing lists of 'near-term expected jobs', what seemed needed was an enumeration of the *durable* foundational skills and knowledge that *all* engineers have *always* needed to possess, based on experience in professional practice over the long-term (i.e. *centuries*). To be useful, such a listing should contain no 'flavors of the month', no matter how apparently worthy at any given time. The hope was that our list could thus be used as a basis for discussing *systemic* changes in engineering education programs required to better align them with truly *strategic* employer needs (i.e. teaching these *fundamentals* should stand any student in good stead, no matter how the world might change in the future).

The list that was constructed in this way has served us well for the past decade and was one of three basic source documents used in framing the 'Student Learning Outcomes' section in ABET Engineering Criteria 2000, approved in 1996. The list has been considered a success in that is has not been found necessary to change anything in it over the decade since it was first published, and much constructive dialogue has been generated by it. It thus remains our basic message to academe regarding *what industry needs* of its graduates. The one item that has been necessary to add is: '*Possess a global awareness*'. Knowledge of a foreign language is one good beginning point in creating a needed multicultural perspective among future graduates.

In applying a similar basic approach to the problem of estimating future workforce needs for the author's own industry, it may be noted that aerospace indeed may now be considered a 'mature industry' (at least in many traditional product lines) even as it continues to change dramatically. This is far from identifying it as a dying industry, however. Indeed, even in the darker times of the recent past, our domestic industry was able to find a multi-billion-dollar-a-year market for its products and services and continued to make a significant positive contribution to our otherwise dismal balance-of-trade deficit. Furthermore, most estimates the author has seen suggest that, taken as a whole, the market for commercial aviation products and services alone over the next twenty years is around three trillion dollars, barring some global-scale catastrophe.

Looking ahead in general terms, the list of fundamentally significant things the aeronautical component of our industry has to do in the coming decades includes:

- Continue to maintain and develop an effective global transportation system that is increasingly safe and secure, and compliant with the needs of our society and our environment.
- Continue to contribute to our national security as threats and effective responses to them continue to change in significant ways.
- Contribute a necessary aeronautics component to the issue of providing affordable access to space, enabling the further exploration of our universe.

All of these topics represent a myriad of challenges and provide a solid base for continued employment of our aeronautics workforce, nationally and globally, even if pursued in evolutionary ways. On a larger, societal scale, however, we can already see some potentially revolutionary developments looming that will dwarf, but also strongly influence, the future concerns of our own industry. These include:

- An increase in the world's population over the next fifty years to a level never before experienced in the whole of human history. One may quibble over the actual numbers, but very substantial further growth and redistribution in world population appears to be inexorable.
- The prospect of *major* climate change, with the contribution of human activity to it being the only real topic of controversy. Examination of the climate record over the past several hundred thousand years suggests that major cyclic climate change has been the norm rather than the exception, and there is no reason to believe that mean temperatures on our planet have somehow stabilized in perpetuity in the current era.
- The finite limit of our global supply of critical resources, specifically fossil fuels [23], but including potable water, fertile soil, etc. Fossil fuels are a non-renewable resource and the effect of an increasingly limited supply must have a very profound effect on the way we imagine future airplane development, as but one of many far larger concerns.
- Confounding attempts to deal with the issues above is the inability or unwillingness of some of the foundational institutions in our global society to change [24]—at least at a rate anywhere near consistent with the need to adapt to the massive challenges we seem likely to face in coming decades. This factor suggests the prospect of increased tensions and strife in our already heavily stressed global society. 'Cultures' simply do not change rapidly, although some do become extinct under extreme circumstances.

All of these issues are global in character and know no national or state boundaries. All are real and, in a worst-case scenario, could conceivably coalesce into a global 'perfect storm' later in this century. Any one of them alone will likely have a serious effect on our global economy and on our own industry. To deal with them, it is going to take all the engineering talent we can muster, merely to ameliorate the worst of their potential effects.

DEALING WITH AN UNCERTAIN FUTURE

In the context above, the question 'how many engineers do we need?' appears in a new and quite different light. While it is impossible to promise jobs at any given time to all those who may choose to enter our profession in coming decades, the author's own conclusion is that *we will need as many engineers in our future as we can hope to create.* It may also be noted that *aerospace* engineers, with a long heritage of experience in 'large-scale system design and integration', are singularly valuable and well qualified to deal with the challenges we can foresee. Continued efforts to develop the sort of 'well-rounded engineers' shown in Fig. 3 thus becomes an imperative, if for no other reason than the one noted by the late Carl Sagan: 'It is suicidal to create a society dependent on science and technology in which hardly anyone [aside from a small élite group] knows anything about science and technology.'

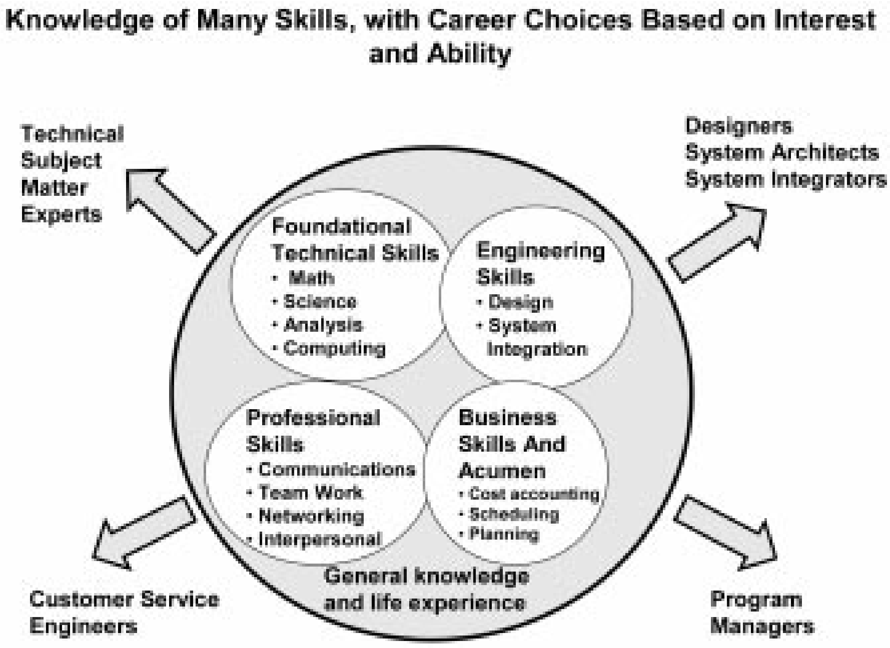


Fig. 3. A 'well-rounded engineer' for the 21st century.

Thus, the next question to be discussed is: 'What can we as educators (individually and collectively) do to prepare for the future of aeronautics?' All of us in our global technical community, whether in government, industry or academe, have a vested interest in contributing to meeting the needs of our society. A good beginning point would be to collectively develop a positive vision of 'what's in it for us' (in terms of technical challenge and contributions to society) for the next generation of engineering practitioners in all the many phases of our enterprise. Others tasks at an institutional level have been discussed at length in earlier writings [8–12] and only need to be summarized in the next section of this paper.

ENGINEERING EDUCATION—FROM CONCEPTION TO LEGACY

Over the past two decades our *undergraduate* engineering education system has been subjected to substantial criticism and calls for reform from industry, from some government sources (NSF, NAE, NRC), and from within academe itself,

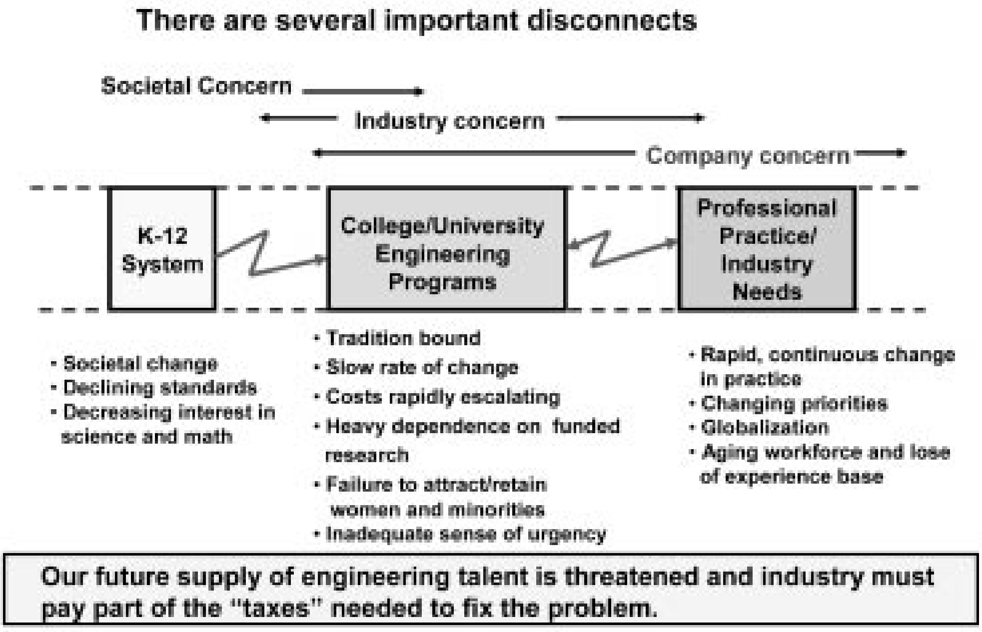


Fig. 4. Our engineering education system under stress.

although the university system is really 'caught in the middle' of a broader system, as shown in Fig. 4.

Some of the more pointed concerns that have been widely expressed include:

1) *Our future supply of engineering talent is threatened*
   - Current engineering education programs are failing to attract and retain an adequate number of students, especially women and minorities (Fig. 5).
   - Undergraduate programs still look more like 'preparation for a Ph.D. program' than 'preparation for professional practice' in too many of our colleges and universities.
   - A too large majority of faculty has little or no significant industry experience and a very limited understanding of rapidly evolving employer needs. (It should be noted here that the Boeing-Welliver Program [14] was created in 1995 to specifically address this issue.)
2) *Engineering education costs a lot for what we get*
   - Engineering education programs are expensive to offer and costs are rising alarmingly, while undergraduate students are not getting full value for their money and too many are turned off by what is offered—especially women and minorities.
   - Employers continue to pay the full (often hidden) bill for teaching graduates what they need to know but are not taught in school. There also is a potential major net saving for industry in investing early in the educational process, rather than paying the bill later. A better sharing of costs and other resources between industry and academe is necessary.
3) *Major opportunities for reform exist but remain to be exploited*
   - Significant advances have been made in our knowledge of how people learn and develop, while new teaching methods and curricular organization have been demonstrated, but have not been widely accepted. Too little has changed in undergraduate engineering education delivery in the past 50 years.
   - New ABET EC 2000 accreditation rules encourage rather than block educational experimentation, although many schools have failed to respond fully to these new opportunities.

For many years, undergraduate engineering education has been based on the implicit (and foolish) assumption that we somehow need to teach students 'everything they might need to know' before they enter professional practice, while trying hard not to lose too many of them in the process. If a new technological area became important in an engineering discipline, faculty would add a course on that subject to the curriculum. This 'throw a course at the problem' mentality [14] forces engineering programs to continually struggle with the question of what to take out of their curricula to make way for the next big item on the often conflicting agendas of faculty involved in graduate research programs and the needs of the employers of their graduates. With too much to know and too little time available to teach it in (as long as *industry* clings to an increasingly archaic engineering degree structure via its hiring practices), academe too often continues to use a

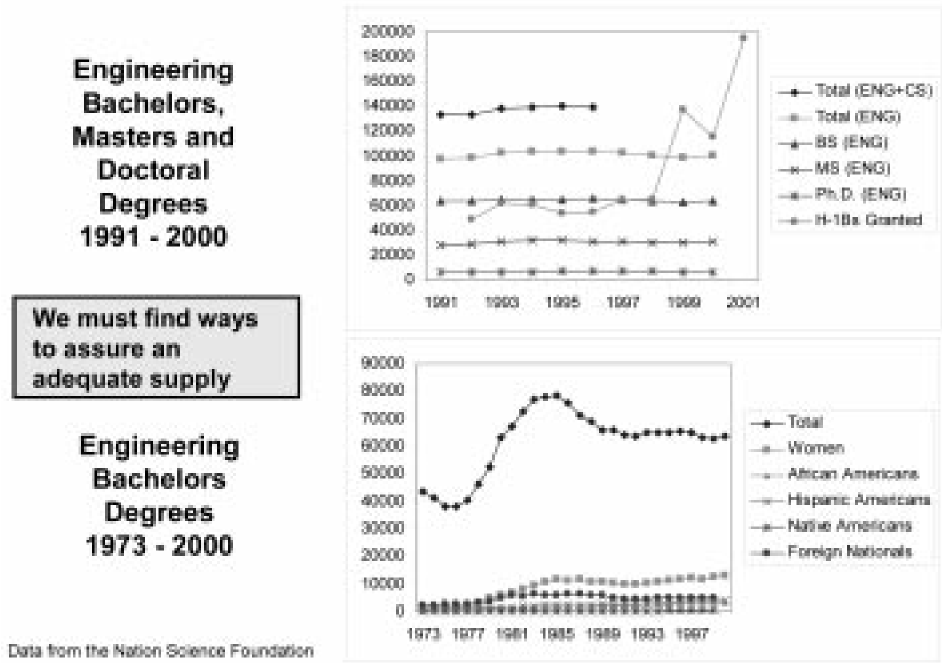


Fig. 5. Our supply of engineering graduates may not suffice.

balkanization approach in curriculum development, with the undergraduate students (especially women and under-represented minorities) too often the casualty of what is offered to them.

One possible solution to the overall dilemma is to expand the box and finally face the fact that the traditional B.Sc. degree is no longer adequate as the entry level requirement for professional practice, and that some sort of five- or six-year program is needed. In whatever creative ways a new engineering degree structure might be contrived, it remains the author's belief that this is at best only a partial solution to the problem.

At the undergraduate level, we need to adopt a modern systems engineering perspective and do a much better job of determining what really needs to be presented (and how to present it) in our efforts to *educate* students to operate in a modern engineering environment, rather than merely thinking about what specific skills they may need in order to gain their initial job assignments, or as preparation for a graduate program in research. Instead of creating courses to meet specific (and too often parochial) needs, we must develop in our students a basic understanding of the *unity* of the fundamental tools and concepts needed for engineering practice rather than providing them with a vast bag of tricks for solving selected problems.

A way to think about future curriculum development might be to proceed from a 'first principles base', as shown in Fig. 6, keeping in mind the quote attributed to the late Theodore von Kármán: 'The *scientist* discovers that which exists, the *engineer* creates that which never was.' The author has long believed that the fundamental purpose of our college and university system is to prepare our graduates to become informed, contributing members of our society, and that engineering is really about design (in the more general sense of open-ended problem-solving). While science and mathematics provide the engineer with much of the basic tool and knowledge suite needed for practice, it is design, and more recently its abstraction into *systems engineering* [7, 11], that is the essence of our profession. In educating engineers for our future, we need to think in terms of a truly student-centered approach with *quality* rather than *quantity* being an objective at the undergraduate level, with much of the specialization in current programs deferred to the graduate level and continued career-long learning opportunities supported by their employers.

What this means to the faculty in our universities is possibly even more work, with little prospect of near-term reward. Changing the goals and rewards for faculty may be more difficult than changing the curriculum they teach, but an effort must be made to attract diverse and well qualified faculties who have strong practice-oriented teaching ability, as well as a desire to perform meaningful research and publish in the right journals. Perhaps most difficult of all is to create a culture and climate where faculty are willing and able to function as a *team*. In doing so, they serve as powerful role models for their students—as a group of *engineers* who are true exemplars of lifelong learning and team-based problem-solving.

SO NOW WHAT?

It is at the individual level, however, that each of us can make perhaps the most important contributions. First, and perhaps foremost, is to recognize that each of us—whether we like it or not—is a role model for others. The image we present to students and the public may be positive, negative or neutral, but we all have an influence we may not fully appreciate. By our professional and ethical conduct, as well as our positive accomplishments,

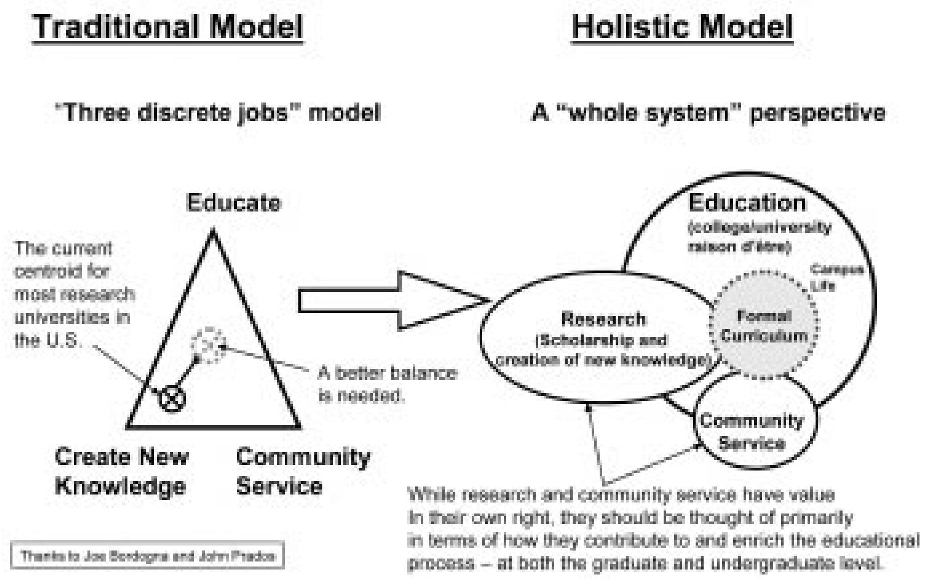


Fig. 6. A better way to view engineering education?

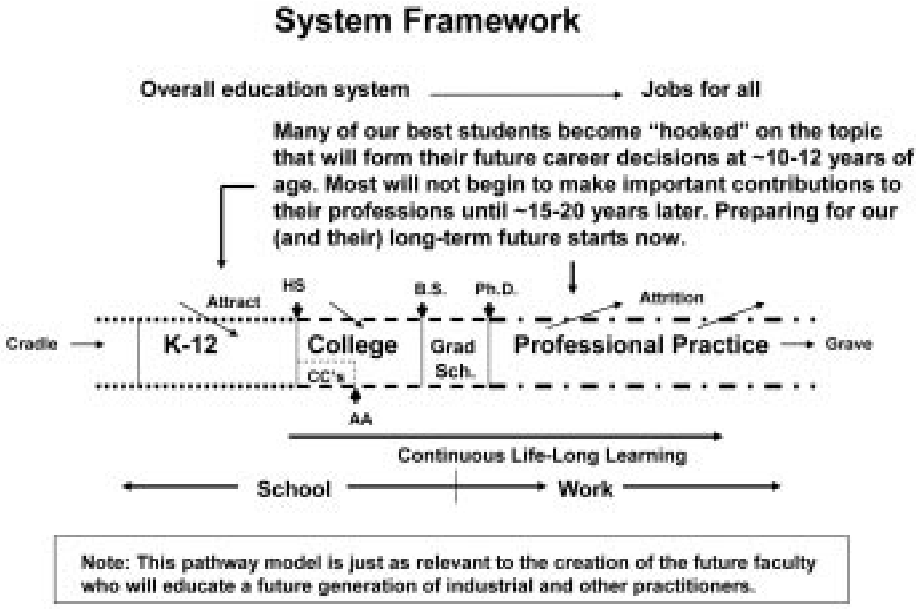


Fig. 7. A more inclusive view of the technical workforce pathway.

we can make a difference. Serving as mentors to others can leverage this in constructive ways.

Actively participating in education is perhaps the single most important contribution any of us can make—whether in a classroom, through service on a school board, or as a member of an advisory committee on issues in which we have needed expertise. The immediate rewards may not be apparent, but the long-term effect can be profound, and some of the benefits can be reciprocal. As a further example, one can examine the whole workforce pipeline (or 'pathway' in currently favored jargon) as shown in Fig. 7 and observe that focusing our attention on the college or university level of education is really too late to have the greatest leverage. Having worked for engineering education reform at the post K-12 level for a number of years, it finally became clear to the author that a necessary beginning point in the subsequent development of future engineering talent (especially women) was to find those things that would create the necessary early fascination with *anything* technical among children at a fairly early age. There are a very large number of factors which influence a student's choices of fields of study and subsequent career decisions as shown in Fig. 1. Over many of these we can have only limited influence. The one thing we all can do, however, is *demonstrate* examples of the work we have done, and the pleasures we have derived from it, to children who may know nothing about what an engineer or scientist actually does. The central objective in this is to inspire and motivate those who might wish to become future engineers and

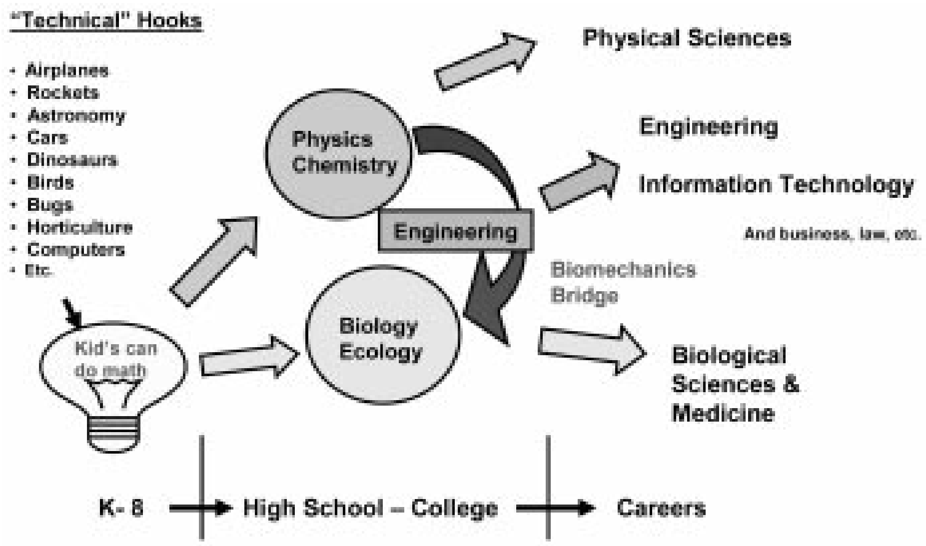


Fig. 8. Hooking kids on math, science and engineering.

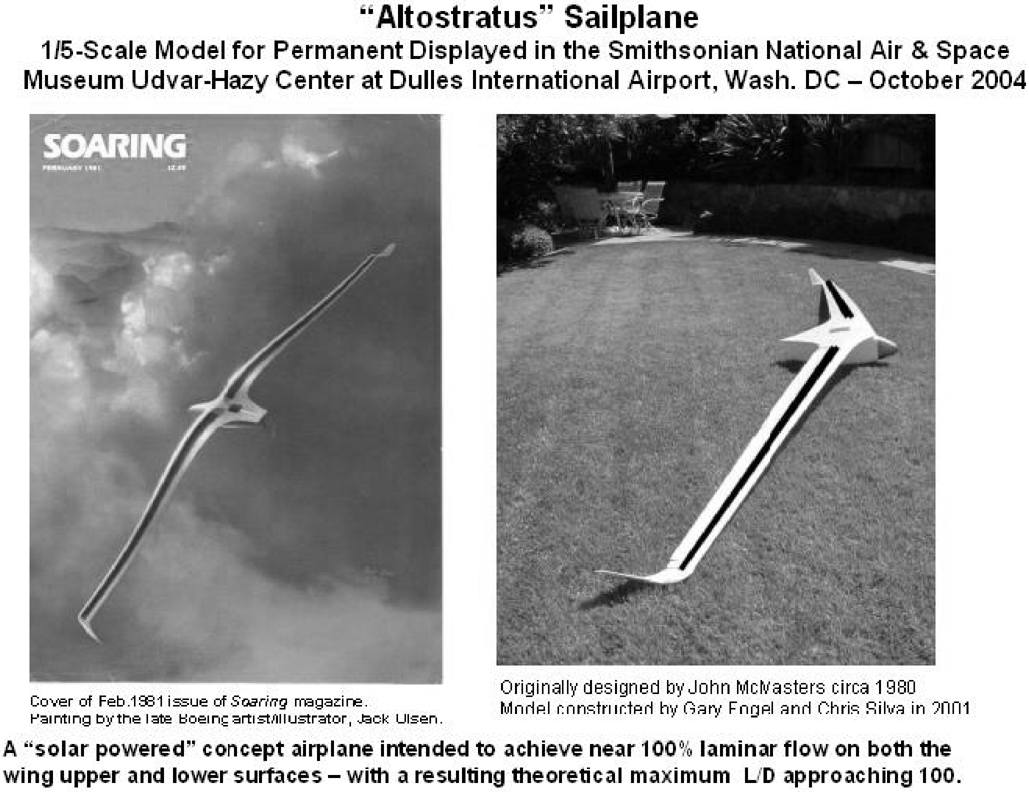


Fig. 9. A 'futuristic' solar-powered sailplane.

scientists—to find the hook, *any hook*, which will create in them a desire to explore a technical topic in further depth and breadth.

Based on the fact that several of the very best aerodynamicists the author knows began with an early interest in astronomy, which then led them to an interest in physics, which in turn introduced them to fluid mechanics and eventual graduate study in aerodynamics, he has been trying a small experiment. This involves creating a portfolio of some of the more interesting and unusual projects he has been involved in at various times over past years (e.g. human-powered flight, sailplanes [Fig. 9] and soaring, hang-gliding, wind turbines, the biomechanics of flight including two robotic pterodactyl projects) and creating a general lecture [5, 10, 21] for audiences at almost any level of interest and maturity. Whether these presentations to students ranging in age from 4th graders through college freshmen have been successful in motivating at least a portion of them to study any particular topic in further detail remains an open question, but the initial reactions have been gratifying. This experiment remains a work in progress, and is but one example of what many others in our profession could do with equal facility based on their own work and experience.

The importance of the sort of 'model airplane project' from the author's portfolio shown in Fig. 9 extends beyond its value as a potential student motivator. After a long period of neglect in the 1970s and 1980s, *design-build-test (*or *validation)* project experience has been increasingly reintroduced in many curricula as an effective means to bridge the gap between engineering theory and practice. Even more is needed, however, and this should become more pervasive from the beginning of the freshman year through graduation (at whatever level) as a fundamental complement to the math and science fundamentals that must remain a core element in any curriculum.

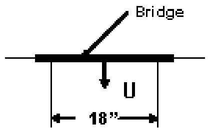
Design-build-test projects are of substantial benefit because they can:

1. Teach students how to deal with realistic engineering problems, the *single* right answers to which are rarely even numbered in the back of the text book.
2. Teach students how to formulate an engineering problem and differentiate between 'requirements' and 'objectives (wishes)'.
3. Require development of both *creative* and *critical* thinking skills and abilities.
4. Demonstrate the design-build-test/validation cycle, and reinforce the concept that *'if you can't build it, you can't use or sell it'*.
5. Introduce and develop project management skills and an awareness of business practices:
   - Budgets and costs (everything one does or makes has both a dollar and an environmental cost)
   - Project planning and scheduling
   - Work and task allocation
   - Documentation requirements
6. Demonstrate the importance of communication

John's Favorite Basic Student Design-Build-Test Project

Problem: Design and build a simple (or complex if you prefer) bridge to span a space between two rectangular block supports placed 18 inches apart. A "roadbed" at least I inch wide shall be provided at end support level. Your choice of construction materials is limited to the following with associated costs of each:

Plain (non-corrugated) cardboard @ $1.00 per sq. in.
White bond paper @ $ 0.10 per sq. in.
Soda straws @ $ 1.00 each (uncut length)
Toothpicks @ $ 1.00 per dozen
Sewing thread @ $ 0.25 per foot
"White" glue (not to exceed ~3 oz.) – free



Performance Criteria: This is a competitive project with grades to be assigned on the basis of the relative maximum values of the performance index (Φ), with:

$\Phi = 10U/W \times C$ U = maximum load carried at structural failure (lbs.)
W = weight of bridge (ozs.)
C = cost of bridge ($)

Notes: Bridges shall be constructed to allow installation of a simple harness at the center of the span on the road bed. The bridges will then be loaded to destruction to establish the maximum value of U. Cost calculations, with supporting documentation shall be provided by the student(s) at time of testing.
[To make the problem more challenging and interesting for advanced students, they may be asked to predict the maximum load their bridge can support at failure.]

Fig. 10. A simple student design exercise.

skills (written, oral, graphical and listening); i.e. 'if you can't explain your solution to someone else, you haven't solved the problem'.

7. Demonstrate the value of team work (synergy and diversity—that two or more diverse heads are often better than one).
8. Expose students to ethical and intellectual property issues.
9. Be highly motivational—and thus help retain students in engineering programs.

Thus even high-school students can be exposed to and encouraged to deal with real societal issues and needs, and developing awareness of these should be part of the project. Finally, and importantly, such projects can be even more educational for the faculty than for the students. They need not even be expensive, as shown in Fig. 10.

One can also extend this line of argument much farther in today's context with regard to aeronautics technology and interests. With the advent of cruise missile technology and more recent interest in the whole range of possibilities 'robot airplanes' offer, we now have the capability of simulating in *hardware reality* a very wide range of aircraft concepts very quickly and affordably, in ways that have not been practical for the past 60–70 years of our enterprise. We now have the capability to build a whole *continuum* of 'X-plane' type vehicles ranging from student project-level model airplanes (using an amazing array of very sophisticated components that are now readily available commercially on the open market) to full-scale proof-of-concept demonstrators of advanced aircraft types. These 'little airplanes' (model airplanes for adults?) also give us the opportunity to address a major auxiliary issue: With the time scale between major new projects increasing at an alarming rate, how do our people (both in professional practice and as students/apprentices) gain the necessary hands-on experience required to design the 'next new thing' from a base of real knowledge rather than purely theoretical studies? Mini-design/build/test 'X-plane' projects have the necessary ingredients to give this range of 'full design cycle' experience—and at an affordable price.

The sailplane model project shown in Fig. 9 demonstrates this possibility. The original circa 1980 drawings for the 'Altostratus' presented a conceptual 'flight of fancy'. The design had purposely been intended to be *statically unstable* and the builders of the model were able (twenty years later) to deal with this and other very challenging issues using standard student-level design software that has now become increasingly available, and electronic equipment purchased from a local hobby shop. While the builders stopped short of trying to model the elaborate solar-powered laminar flow control system envisioned in the original design (and thus transform it into a DARPA-type project of perhaps a mere 20 years ago), this too is now coming within the reach of even hobbyists and student teams, and suggests all sorts of amazing future opportunities to explore regions of the flight regime and configuration design space that few have been able to reach before—in hardware reality terms, without excessive risk to either life, limb or one's bank account. The opportunities here are truly marvelous and almost unlimited.

FURTHER THOUGHTS ON ENHANCING ENGINEERING EDUCATION

While there are many opportunities to enhance our engineering education system, it has long been

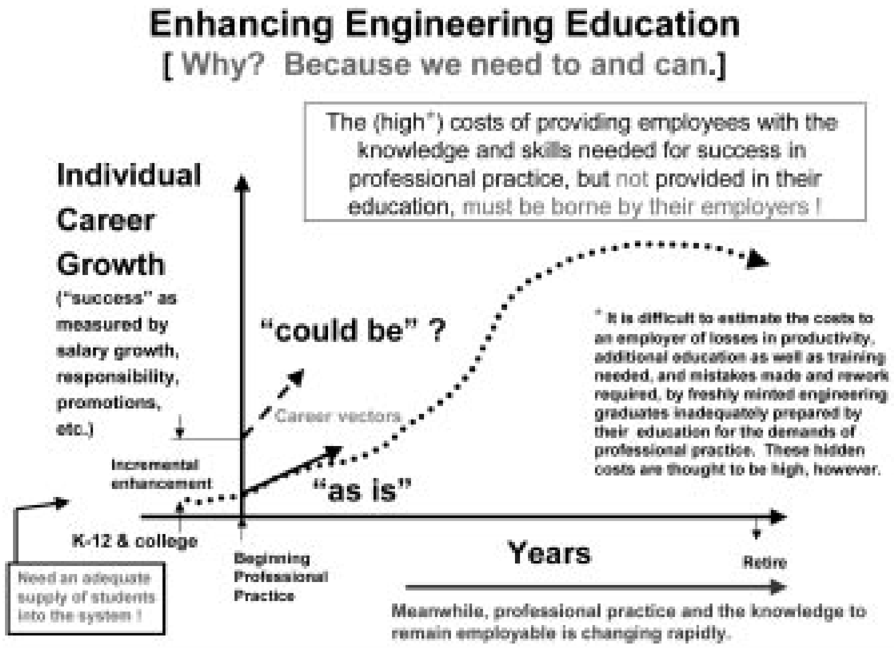


Fig. 11. An industry view on the need to enhance engineering education.

the author's conviction that this is a shared responsibility between industry, government and academe. Industry has be an active partner in this endeavor, if for no other reason than that shown in Fig. 11. While industry pays much lip-service to the need for reform and continually criticizes the 'lack of practical education' our students receive, we have too often proved to be fair weather friends (with enthusiasm dependent on the particular phase of the business cycle any specific company may be in) in providing the necessary resources to sustain meaningful reform efforts [14, 22]. It may be further argued that industry has even been something of a 'counter-productive force' in seeking reform by clinging, as noted earlier, to hiring practices that continue to promote the baccalaureate (B.Sc.) degree as adequate for entry into professional practice. Many have come to believe that a 'practice-oriented' Master's degree would be a more appropriate minimum requirement in today's environment.

Industry further contributes to the 'education problem' by placing undue emphasis on grade point average (GPA) as an important metric in making hiring decisions. While not alone in this mischief, it is clear that industry's contribution to the creation of a sort of 'GPA *uber alles*' mentality in our students (which actually begins well before most students enter college) can be destructive of sound educational practice and student learning. This observation is based on the author's own experience in attempting to offer students the luxury of actually spending class time *learning* something beyond mere facts and information that can be easily regurgitated in an examination. The first question asked by these students, even at the beginning freshman level, is: 'Are you going to grade us on this stuff?' When told that learning rather than grades are the author's primary concern, the students generally say rather sheepishly that they are taking several other really tough classes in which they *will* be graded and thus cannot afford the time to contemplate what the material presented really means. This has happened too frequently in recent times to be a 'singular experience' for at least this author, and it makes one who is committed to education cringe. When combined with concomitant, pervasive 'grade inflation', the problem of finding meaning in grade point averages as a metric for much of anything other than a student's test-taking ability and quality of short-term memory is further exacerbated.

Concerned about the GPA issue as it might relate to a graduate's actual work performance in professional practice, two of the author's management colleagues performed an experiment in the early 1990s. The first involved comparing the undergraduate grade point averages for 460 aerodynamicists employed by Boeing at that time with the metric used to rank these employees for retention (in the event layoff might be required) and merit pay, as rough measures of the employees 'value to the company'. The result was a vast 'scatter gram', with the observation made that a fair 'least-squares circle could be drawn around the data'. The GPAs in this sample ranged from a low of 1.8 to highs of 4.0 on a 4-point grading scale. (Amazingly, the holder of the 'record' 1.8 GPA was ranked as one of the 'most valued' employees after twenty years with the company.) While hardly a scientific survey, and colored to some degree by issues of 'seniority' within the population sample, there was no apparent direct correlation between school performance as measured by GPA and subsequent work performance. It also turned out that within this sample, by the time a graduate had been out of school for three-to-five years, there was little observable correlation between an individual's work performance and the schools from which they had obtained their degrees. Doubting the results of this first analysis, a second manager repeated it with a sample of 120 structural dynamicists, and obtained very similar results.

Certainly, all these graduates were taught an adequate measure of the basic math and physics needed to gain employment and do their work, but as a rule their performance on the job has not correlated well with their academic records alone. Legal and privacy issues, plus the fact that few of our companies employ a statistically significant sample of the graduates of any one university program, has led many in industry to eschew offering universities work performance data on their graduates for ABET EC 2000 evaluation purposes.

Serious flaws in other commonly used metrics such as the often cited rankings of university programs prepared by *US News and World Report* can also be identified in connection with the problem of judging the adequacy of current university undergraduate education programs in this country when making hiring decisions. The problem is then multiplied as many of our companies 'go global' and must confront hiring in the international market. The school-to-work gap issue is further discussed in an excellent recent paper by a friend and colleague, Dr. David Wisler of GE Aircraft Engines [22], and also accounts for the heavy emphasis on the so-called 'soft' (or much-preferred 'professional') skills in the Boeing list in Fig. 2.

CONCLUSION

Much has been accomplished in the past two decades in changing our system of engineering education in this country, but so much more needs to be done, especially in creating truly student-centered undergraduate programs that attract and retain women and under-represented minorities while maintaining the high standards required to sustain the integrity of our profession.

Having been an active member of the engineering education reform movement for many years, the author has found it necessary at times to be a harsh critic of the current education system in this country. This has led some readers of his earlier writings to assume that his criticisms of the *system* are aimed at them individually, and that he has some sort of axe to grind. Neither is the case, to the degree to which one can be truly objective about one's own motivations. It has been a long-standing belief that, despite all criticisms, we in the US continue to have arguably the best *graduate-level* engineering education system in the world. It is toward the *undergraduate* system that most criticisms have been directed. It is also true that an amazing number of truly dedicated individuals continue to work extremely hard under heavy constraints to give their students (at any level) the best education possible. One has to have been a working-level faculty member in a modern research university to fully appreciate what these individuals strive to accomplish under often difficult conditions. The author has the utmost regard and respect of these people, and considers many of them to be among his most valued friends and colleagues. It remains a fact that in this country, teaching (at any level) is still one of the most challenging, important, and sadly under-respected vocations in our society. The tired old saw, 'Those who can, do; those who can't, teach', infuriates every time it remains too often heard.

In this same vein, if one were to address one single, 'most important' factor (such as those in Fig. 1) which can significantly influence a student's choice of studying and then practicing engineering, it would have to be: enhancing the public perception and understanding of our profession. Once we, as a community in industry, government and academe, succeed in creating a positive image of engineers as 'society's technical problem-solvers' (and thus uniquely distinct from our peer scientists) in the minds of the media and the lay public, we will have taken a long step forward in establishing a necessary foundational base for further engineering education reform.

> 'I don't know why people are frightened by new ideas. It's the old ones that frighten me.'
>
> John Cage, American composer

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John H. McMasters joined Boeing Commercial Airplanes in 1976 as a research aerodynamicist and currently serves as a program manager for the Ed Wells Initiative, a joint program between Boeing and the Society of Professional Engineering Employees in Aerospace charged with enhancing the excellence of the SPEEA-represented Boeing technical workforce. He also has served since 1990 as an Affiliate Professor in the Department of Aeronautics and Astronautics at the University of Washington in Seattle. His professional and avocational interests run together over a broad range of topics including: low-speed/high-lift aerodynamics, airplane design, biomechanics of flight, paleontology, cognitive psychology, and engineering education. An Associate Fellow of the American Institute of Aeronautics and Astronautics, he twice served as an AIAA Distinguished Lecturer, from 1992 to 1994, and again for 2002–2005. He was selected in 2004 to be the 29th SAE/AIAA Littlewood Memorial Lecturer, and is a Sigma Xi Distinguished Lecturer for 2005–2007. Dr. McMasters holds B.Sc. (1961) and M.Sc. (1962) degrees from the University of Colorado at Boulder and a Ph.D. (1975) from Purdue University, all in Aeronautical Engineering.