Boeing-University Relations - A Review and Prospects for the Future

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Abstract

The Boeing Company has been noteworthy within the aerospace industry for its ambitious university relations program originally conceived in the early 1990s. This program has aimed at not only creating strong company relations with universities important to its business interests, but also to lead broader industry efforts to enhance engineering and related technical and business education programs across the nation. This paper reviews the development of the Boeing program, discusses important lessons learned from the overall effort, and outlines prospects for future developments. Specific program elements are discussed. Key in this has been the Welliver Faculty Summer Fellowship Program which, after a decade of operation, can be considered to have met its initial expectations. Reasons for successes and failures will be discussed and opportunities for future developments will be identified. Alumni of this program have enhanced the relevance of engineering education by incorporating industry perspectives, and industry has benefited from the perspectives and insights brought by the faculty participants. The paper will survey the results from the program and relate them to the needs of the present and future aerospace industry and engineering academe.

Introduction

Consolidation, new technologies and globalization have continued to bring new priorities and rapid change to the aerospace industry. Through these interesting times, the workforce and infrastructure have been aging at an alarming rate. Traditional means of experience-building with needed knowledge retention and transfer have been severely strained, as traditional processes and time-scales for developing products and the associated skills have evolved. Partially anticipating these changes in industry, Boeing took the lead in highlighting the need for change in their supply chain of talent – the university system. This need was articulated and pursued through its ambitious university relations program, originally conceived in the early 1990s. This program has aimed to create strong company relations with universities important to its business interests. It has also led broader industry efforts to enhance engineering and related technical and business education programs across the nation. As new challenges continue to loom, this paper reviews the development of the Boeing program, discusses important lessons learned from the overall effort, and outlines prospects for future developments. The authors' experience is used to develop both an industry and a university perspective, not to be attributed exclusively to one or the other. In some important particulars, the authors agree; on other topics they may not. In sum, these convergences or divergences of opinion may be considered reasonably representative of the current state of affairs in relations between academe and industry in general, and our observations and opinions are offered in this context. Despite any differences in opinion, the authors remain friends and share a mutual passion for enhancing engineering education.

Industry Perspective

Concerns about the future of engineering education were identified by many in the late 1980's and early 1990's. Many of the more pointed concerns expressed at that time related to *undergraduate* rather than graduate-level engineering education. These concerns are to some degree still active and include:

- 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. Undergraduate programs still resemble "preparation for a Ph.D. program" rather than "preparation for professional practice". Large majorities of existing faculty members have little or no significant industry experience, and thus have little understanding of rapidly evolving employer needs.

- Engineering education costs a lot for what we get. Costs are rising alarmingly, while undergraduates are not getting full value for their money. Too many are turned off by what is offered. Employers continue to pay the full (often hidden) bill for teaching graduates what they need to know, but are not taught in school. There is a potential major savings for industry in investing early in the educational process, rather than paying the bill later.

- 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[1, 2], but have not been widely accepted. Too little has changed in undergraduate engineering education delivery in the past 50 years.

Much thought has been devoted in both industry and academe to the future of our enterprise and the technical workforce needed to support it[3]. However, predicting an unknowable, but likely continually volatile future presents many problems. In such situations it is sometimes valuable to examine current events and concerns in terms of much longer historical time scales. In this way one may attempt to discern basic trends and durable characteristics that might provide useful guidance for our future, and avoid the dangers of extrapolating from a possible bubble or trough in any evolutionary process. With this longer-term perspective in hand, one then may examine what new developments might occur which could produce changes in the 'old way of doing business'. The futurist's role is thus to examine "what *could* happen (if wanted and no unknowable events intervene)" rather than attempt to predict the future.

One successful example of this approach was its use in the construction circa 1993-94 of the Boeing list[4,5] of "Desired Attributes of an Engineer" (Fig. 1). The original purpose in 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 posses, 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.

Boeing List of "Desired Attributes of an Engineer"

- **A good understanding of engineering science fundamentals**
  - Mathematics (including statistics)
  - Physical and life sciences
  - Information technology (far more than "computer literacy")
- **A good understanding of design and manufacturing processes** (i.e. understands engineering)
- **A multi-disciplinary, systems perspective**
- **A basic understanding of the context in which engineering is practiced**
  - Economics (including business practice)
  - History
  - The environment
  - Customer and societal needs
- **Good communication skills**
  - Written
  - Oral
  - Graphic
  - Listening
- **High ethical standards**
- **An ability to think both critically and creatively - independently and cooperatively**
- **Flexibility. The ability and self-confidence to adapt to rapid or major change**
- **Curiosity and a desire to learn for life**
- **A profound understanding of the importance of teamwork.**

Diversity – wanted and needed !

http://www.boeing.com/companyoffices/pwu/attributes/attributes.html

Figure 1: Desired Attributes of an Engineer.

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. New ABET EC 2000 accreditation rules encourage rather than hinder educational experimentation[2], although many schools have yet to fully realize and exploit these opportunities. In general, it has not been found necessary to change anything on the list 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 their graduates. If one were to modify it today, the one item that is probably necessary to add is: "*Possess a global awareness*". Knowledge of a foreign language is one good beginning point in creating a needed multi-cultural perspective among future graduates.

Enhancing Engineering Education – From Conception to Legacy

For many years, undergraduate engineering education has been based on the implicit assumption that we must attempt 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[3]. As new technological areas became important in an engineering discipline, new courses would be added to cover them. While this has caused constant rethinking of what constituted "essential fundamentals", it has also resulted in curriculum compression – sometimes to extreme levels. Faced with pressure to add material, reduce time, and satisfy the demands of the (sometimes archaic) industry hiring practices, academe too often resorted to a balkanization approach in curriculum development.

One possible solution to our overall dilemma is to make the entry level requirement for professional practice a 5- or 6-year program. This is at best only a partial solution to the problem. While science and mathematics provide the engineer much of the basic tool and knowledge suite needed for practice, it is design, and more recently its abstraction into *systems engineering*, 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.

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 a vast bag of tricks for solving selected problems.

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 life-long learning and team-based problem solving.

Boeing's Efforts to Be Proactive

Having identified and spotlighted the issues, circa 1993-94 Boeing began efforts to help make a difference. The structure of what became the suite of "Education Outreach" programs and the roles of the different components are shown in Fig. 2. Developed under the auspices of what is now the company offices-level University Relations Process Council in conjunction with a select group of faculty representing a cross section of universities significant to company interests, this suite of programs and initiatives included:

- An annual series of **Boeing-University Workshops** held from 1994-1998, which brought together Deans and Department Chairs from approximately sixty colleges and universities across the country to discuss relations between their institutions and the company, share mutual concerns, and develop ways to resolve them in cooperative ways.

[Note: The Boeing list of the *"Desired Attributes"* (Fig. 1) was developed specifically to aid this type of discussion.]

- The **Boeing Outstanding Educator Award Program** [Note: This program began in 1995 and ended in 2001 with the advent of the similar but more generous Gordon Prize offered under the auspices of the National Academy of Engineering.]
- Leadership in the formation of the **Industry-University-Government Roundtable for Enhancing Engineering Education [IUGREEE]** in 1995. The IUGREEE[6] played a significant role in developing a base of industry support in the formulation and subsequent adoption of ABET Engineering Criteria 2000 in late 1996.
- The **Boeing-A.D.Welliver Faculty Summer Fellowship Program**
- The **Boeing Fellow on Campus Program**

These final two program initiatives were developed as reciprocals of each other and were based on a widely acknowledged "anomaly" in our system of engineering education, i.e. a very substantial percentage (70-80% circa 1993-94) of engineering faculty have had little or no industry experience and are thus seriously limited in their ability to prepare graduates for the realities of professional practice outside a research environment. The thought was that an effective way to bridge the gap between the interests and needs of academe and industry would be to create "cultural exchange" opportunities of mutual value to both Boeing and universities important to company strategic interests in education (and ultimately recruiting). Details of these two programs, one a success and the other a "failure", are discussed in the following sections. Some discussion of Boeing experience with undergraduate student Summer Intern Programs[7] is also included, since these programs can be valuable in the current context, and they work well.

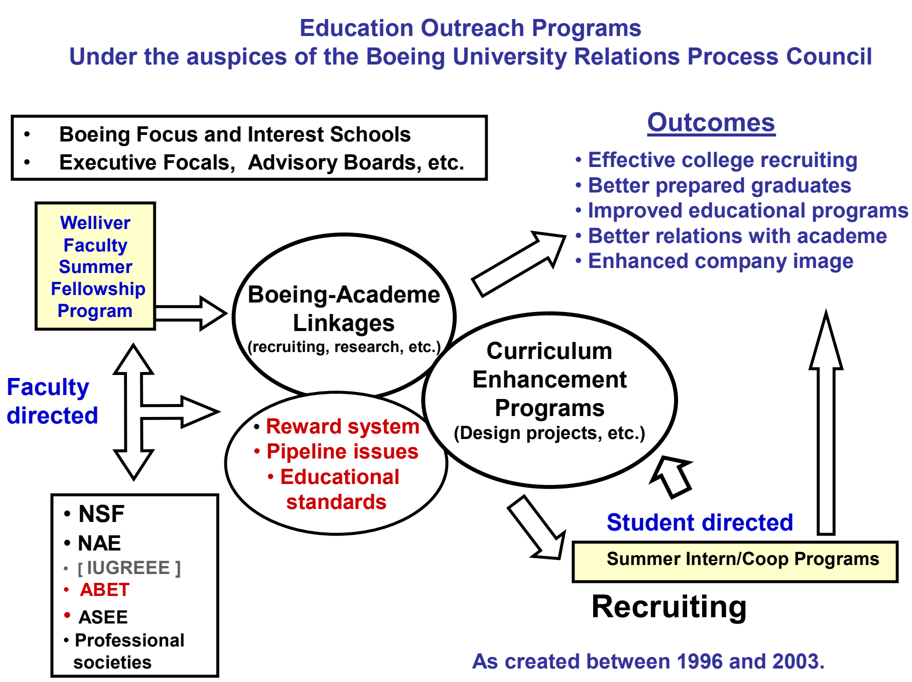

Figure 2: Boeing's Education Outreach Programs.

The Boeing-A.D.Welliver Summer Faculty Fellowship Program

The Boeing - A. D.Welliver Faculty Summer Fellowship Program (WFSH) was created in 1994-95 to provide faculty with a better understanding of the practice of engineering, information technology and business in industry. The Program is named in honor of the late A. D. "Bert" Welliver[8], a former Boeing Corporate Senior Vice President of Engineering & Technology, who was recognized throughout the aerospace industry for his vision and leadership in promoting a close working relationship between industry and academia as well as between engineering and manufacturing.

The Program has two primary objectives:

- To provide faculty from a broad range of schools with a better understanding of the practice of engineering in industry, and of the business realities of that practice.
- To influence the content of *undergraduate* education programs in ways that will better prepare tomorrow's graduates for the practice of engineering in a global industrial environment.

Throughout its history[9], the primary emphasis has been on enhancing *undergraduate* programs and developing a better alignment of curricular content with industry needs. Little attention (too little in the opinion of some) has been paid to corresponding needs to enhance graduate programs, nor to the potential for exploiting and developing longer-term research opportunities of mutual interest to Program participants, the schools they represent, and the company. This latter opportunity has become an increasingly significant tertiary objective of the program in recent years.

The approach taken has been to provide an 8-week exposure to the business realities of the industrial workplace to a group (9-12 annually depending on business conditions) of competitively-selected Faculty Fellows. The WFSF targets faculty members at the Associate Professor level or above (i.e. those with tenure). Those at the Assistant Professor level or below are generally asked to reapply at a later date once tenure has been granted. Boeing pays participants a salary equivalent to average faculty compensation rates, a per diem, and travel expenses incurred during the duration of the WFSF.

Each Faculty Fellow is assigned a company "mentor" who works with them to tailor the WFSF to meet their individual needs and interests, and then shepherds them through the overall program. The first week of the program is held at a selected plant site and concentrates on giving the group of Faculty Fellows a broad overall familiarity with Boeing through briefings, tours and interactions with company personnel. During Weeks 2-6, Faculty Fellows are dispersed individually to several plant locations across the U.S. and given "shadowing assignments" that allow them to freely interact with several levels of technical and management employees (from recently-hired engineers through company executives). The final week of the program brings the Faculty Fellows together again at a second major plant site and culminates with wrap-up briefings, tours, and the Fellows' reports to Boeing managers. The first required report to Boeing is a collaborative report emphasizing potential process improvements within the company, based on the Fellows' observations during their six weeks of shadowing assignments. The second report required is each Fellow's individual plan for future efforts on his or her campus based on lessons learned during the entire Program.

After ten years of operation, the Program has generally been considered a success in meeting its (limited) objectives. From its inception, it was hoped that programs similar in concept and intent to the WFSF would be emulated by other companies throughout the country as a significant means to encourage *systemic* change in engineering and related education programs of interest to us all. To date, however, the program remains *unique* to Boeing (notwithstanding the existence of industry-university *research* focused efforts like the NSF GOALI program), and now, after a decade of successful execution, has generated 107 alumni from about sixty colleges and universities (including HBUC/MIs and institutions of higher education in Australia and India).

Boeing Fellow on Campus Program

In creating the WFSF, it was also recognized that its reciprocal could be of considerable value, and thus the concept of a Boeing Fellow on Campus Program was developed in parallel. Many engineers and potential managers avail themselves (often at company expense) of university-based continuing education opportunities as part of their career and professional development. Sending them back to school as "adjunct" or "visiting" faculty, rather than as mere students, seemed a much more effective use of their talents and expertise – i.e. the "teacher" can often learn much more than the students in the education process and every one (students, faculty, and the industry individual) can thus gain from the campus experience provided by the *extended residence* of engineers from industry.

A further motivation for developing this program was the observation that there was (and remains) as much ignorance of the realities of academe on the part of our industry colleagues as we perceived there to be on the part of faculty about industry. Thus, if sustained relations with academe were to be established, a working knowledge of the constraints and demands on faculty seemed essential, and the best way to get it would to become resident "visiting instructor /students" for an extended (though limited) period of time – e.g. a minimum of an academic quarter or semester, depending on how a specific school was organized.

With these notions in mind, a program was constructed which identified suitable candidates from Boeing to be fielded to willing schools in programs considered important to the company. What had not been adequately appreciated, however, is the rather brutal nature of the "industry reward system". While very different from the university "reward system", individuals who embark on "extracurricular activities" like our proposed Fellow on Campus Program too often find that "out of sight, out of mind" for a period of more than a couple of weeks could have significantly adverse career consequences. Despite careful work with both the schools and the management chains for the initial trial candidates for the program well before the actual assignment began in 1996-97, the experience proved less than satisfactory for almost all involved. Thus, with the exception of a few more modest attempts to repeat the program at later times, it has not been continued. Work done with other companies on this type of project suggests that this situation if far from unique to Boeing. The conclusion from this has been that the gap between academe and industry – at the working level – is even wider than had been thought, and that much of the problem lies on the *industry* side of the equation, rather than being due to academic recalcitrance.

Boeing Summer Intern Program

A more traditional and long-standing "success" in bridging the school-to-work, industry-academic gap has been co-op/intern programs, generally involving undergraduates. Many companies offer such programs and many find them to be as beneficial as the Boeing program that has been offered for several decades. If approached in a proper way, such programs seek to provide a suite of experiences and knowledge *complementary* to what a student is exposed to in his or her academic program of study. It is a relatively easy way for industry and academe to cooperate in this with benefits to all (the school, the students, and the company) in addition to providing financial aid and resume` material to the student. Boeing operates a large Summer Internship program, with over 300 undergraduates in the Puget Sound area alone in 2004. Faculty interaction with this program varies, from "non-existent" to "close". Follow-up or leverage at the university achieved through these internships is limited, as valuable as they are in the recruitment process.

University Perspectives

From the perspective of junior faculty of the late 1980s and early 1990s, much of Boeing's articulation of the needs came across as "preaching to the choir". The reaction was a mixture of agreement and frustration – agreement with Boeing's objectives, and frustration that the changes already instituted at great pains (and often in the face of resistance) were not being recognized. A few general beliefs of that time are indicated below:

- Engineering curricula and modes of pedagogy have evolved through decades if not centuries of experience, and it would take a tremendous amount of energy and dangerous experimentation to move from the present to a new stable optimum.
- Initiatives from NSF and industry had often come and gone, but academic curricular and reward structures were grounded in firm realities, which would outlive such transients.
- Industry's traditional attention span (months or at most a particular business cycle) was not a reliable basis to sustain curricular changes whose effects would take a decade to see.
- The Attributes list (Fig.1), though couched in general terms, was seen as pressure to inject even more constraints into the curriculum.[*]

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[*] *This last point is because the default method for addressing perceived curricular deficiencies is to add new "required credit-hours" in the specific topic area indicated. Thus, new "required courses" in Statistics, Ethics, Teamwork and Communications would quickly add up to another 12 credit-hours of constraints, squeezing out substance and time from the ever-decreasing "core curriculum" where students learned "hard engineering". For instance, in a 205-quarter-credit-hour aerospace curriculum, roughly 60 hours were already devoted to state-mandated subjects, leaving only an effective 9 quarters for core technical subjects including mathematics, physics and chemistry. Faculty generally assumed that such new "requirements" would increase the liberal arts credit-hour allotments, rather than be woven into their already-crushed time to teach core engineering as was intended by the creators of the list. This was greeted with the same love and anticipation with which some of us in academe viewed our Advisory Boards' insistence that we add a Required core 3-credit course on "Total Quality Management".*

Changes in Academia in the Past 15 Years

NSF Initiatives

There have been major changes in academia since the late 1980s. Calling for funding of engineering education reform at levels comparable to usual scientific research funding, the National Science Foundation set out several initiatives. These included university coalitions, institutional curricular reform projects, laboratory/experiential learning grants, math /science /engineering/technology digital libraries, curriculum-research integration, and incorporating results from psychology and cognitive science. These programs have collectively changed institutional *attitudes* towards instruction and curricular improvements. Rather than fundamental changes or revolutions, *enlightened practices educated by example* have permeated the reward structure sufficiently to encourage faculty to undertake curricular innovation.

One result of NSF funding was the creation of institutional resources for educational assessment. The new initiatives brought media attention. The ranking system developed by "U.S. News and World Reports" on detailed university programs rendered the "traditional reputation" based on Deans' opinions unsafe as a guarantor of parental preference in undergraduate admissions. Quantitative metrics induced improvements that would influence rankings – measures to improve freshman retention, classroom infrastructure, and internships for undergraduate research participation. The collateral damage was that expectations of funding level per faculty member also rose dramatically as administrators saw figures for the "leading" institutions. For instance, \$100K per faculty member per year was considered high in the 1980s. Today \$600K/yr is not considered remarkable, in a far more intensely competitive environment – implying a huge increase in the demands on time spent on proposal-writing and money management. The primary metric of quality is still size - not wisdom - of the annual expenditure of funds. In this respect, industry and academia have indeed aligned themselves very well. On another level, the laudable inclusion of teaching as a primary criterion for promotion and tenure has triggered an unintended but horrifying epidemic. Today an "effectiveness score" above 90% given by pre-final-exam student opinion is used as the sole definition of excellent teaching in most engineering schools (mathematics and physics teachers have been forced to demand better metrics). This threatens to crush any spirit to insist on rigor and challenge in the "harder" courses, and to promote the safe strategy of "happiness for all". The effects of this on the future U.S. ability to excel in a global market, remains to be considered.

Design of Large-Scale Systems in the curriculum

Since the early 1980s, the computer had already enabled us to pose more "realistic" and "open-ended" problems in classes – even in large classes. This was a real deviation from the model of individual students working out compartmentalized problems in theory classes. Teams of two became the norm in these assignments, as a way to ensure individual effort while encouraging teamwork (and halving the number of assignments to be graded). We have since come a long way in using technology to enable large, realistic open-ended assignments. However, the Capstone Design course so lauded by industry, rarely used the skills learned in these courses, partly due to lack of awareness, partly due to the pressures of time, and partly to the isolation of Design Professors from the research environment where one had to keep learning new technology. Thrust into sudden and *uncritical* prominence by ABET and industry pressure in the '90s, the capstone design course in its traditional form became in some sense a millstone around the necks of the faculty who wanted to make real advancements, by setting a rather low bar of technical competence for students. Capstone courses are immensely popular among undergraduates as they impart "real-life" role-playing opportunities. The downside is that the actual level of thinking, innovation and hard technical problem-solving that occurs in these courses is not high, as attested by alumni who call it the easiest (while most time-consuming and "fun") course in the curriculum[†]. Technology and the emphasis on teamwork have served to help bridge the disconnect between the upper-level courses and the capstone design course. The use of large computer programs for design optimization required students to be organized into larger teams. However, the efficiency of such teams in the learning process remains a big question today. Radical efforts have included a single design project vertically integrated through the 4-year curriculum, but generally, faculty have tried to address this concern outside the regular curriculum through "Design-Build-Fly"[10] or research-design team experiences.

Systems Engineering

There is huge apparent demand for people with "Systems" training, but no clear consensus has emerged regarding the balance between core fundamentals and systems engineering in the undergraduate curriculum. At the same time, Systems education has blossomed at the graduate level with many tools and techniques being developed, and common threads being refined into research areas in Systems Design. Presumably, this will result in good undergraduate textbooks or other pedagogical resources and experience being developed, as prelude to incorporating these concepts in the core curriculum.

Independent problem-solving opportunities

A major cultural change that occurred somewhat independently of industry efforts, is the reduction of institutional resistance to the idea of involving undergraduates in research. The NSF's Division of Experimental and Laboratory-Oriented Studies (DELOS) deserves part of the credit for this, as proposal writers sought innovative ways of involving undergraduates in unique experiential learning opportunities. The ILI/LLD programs led the way in enabling undergraduate involvement, followed by the REU (research experiences for undergraduates) programs, and supplemental funding for NSF grantees to involve undergraduates. The result was that enthusiastic and determined faculty were able to ward off the pressures to "spend more time with graduate students and less with undergraduates", since undergraduate research was clearly bringing projects. However, the pioneering experiments to bring undergraduates into research programs were driven by need to find and train excellent future graduate students, and to provide better employment versatility during the aerospace recession of the early 90s. *The implications of*

[†] *This point was proven when much of the content of the first traditional aircraft design course at Georgia Tech was re-packaged to be taught and learned very successfully by first-semester freshmen who had taken no engineering courses at all. The intent here was to enable the senior design course to get much deeper into innovation and analysis, but the potential for vertical and horizontal integration opened by this demonstration remains largely untapped.*

such programs remain largely unrealized by industry today, though the alumni of such programs are to be found throughout industry, obviously being successful in the workplace.

Communication skills

Most students now have the opportunity to participate in team exercises demanding technical communications in multiple forms. Presentations, group discussions, case studies and reports on large assignments, are all examples of such requirements. Various team competitions provide intense experiences demanding excellence in communication skills. However, it remains difficult to close the feedback cycle in improving communication. We have not progressed from the stage of dumping several "expert-recommended" communication strategies, to the stage of tailoring communications to achieve clarity of understanding with different audiences.

What has suffered

The dissatisfaction expressed by industry has led to some misdirected changes as well

- "Mandated" courses drive severe compression of the core engineering curriculum. It is too easy to justify spending hours on such "mandated" topics as Ethics and Communication Skills – whereas spending time on eye-glazing derivations, and learning to solve differential equations, is not what the Real World wants. Thus, few see why it should take longer to learn, say, Fluid Mechanics than a language – to reach the level of a conversationalist. The difficulty is that this level of competence is dangerously inadequate in an engineering graduate. Much more insidious is the effect on the out-of-class learning time available to students. For instance, one devotes a single three-semester-credit hour course today to learn low-speed aerodynamics – what used to be spread across 7.5 quarter-credit hours in two courses. In this course, the student starts from (and re-learn) high school physics, and uses differential equations in problem-solving for the first time. In the same semester, student also takes 12 other credit hours. To the student, it appears logical that the 3-hour introductory foreign language course and the 3-hour aerodynamics course should demand exactly equal amounts of learning time and effort. The expectation that students must read textbooks has been rendered impractical – students view this as an unreasonable expectation imposed by poor classroom teaching. *Thus we are increasingly likely (though we will strongly deny that this has ever happened on our watch) to graduate aerospace engineers who know aerodynamics to the same level as they know, say, introductory Spanish.*

- The clamor for better communication skills has been interpreted in many places as *carte blanche* to indulge in "PowerPoint Engineering" – vast amounts of time and effort expended on appearance and delivery as opposed to intellectual content. Senior industry professionals strongly caution us today that clear communication of issues requires strong understanding of the fundamentals, much more than just presentation skills.

- We have back-pedaled for a decade or so in the drive to instill deeper analytical abilities and more rigorous technical competence. The idea that polished presentations and "soft" sales skills equate to leadership in engineering, is perhaps costing us steeply in global competition. Today, it is becoming evident that the success of engineering in other countries such as Japan, China and India may be due not just to "cheap labor" but also to "better product for the money". This has occurred in one industry after another, exemplified by the evolution of Japanese automobiles from their "reputation" for cheap, flimsy vehicles, to dominance of objective quality rankings. The same occurred in the semiconductor industry. Similar developments are becoming evident in the European aerospace industry, which has proved to be faster at adopting technical innovations into advanced products than their American counterparts.

The implications to engineering education are yet to be realized – but it is evident from experience that engineers graduating from other nations are quite well-prepared to succeed in American graduate schools. Today it is also becoming evident that uncompromising emphasis on mathematical reasoning and analytical ability are keys to implementing innovations in advanced technology. Graduates from the leading European and Asian institutions come with superb mathematical skills. The superstitions which held that foreign schools teach rote learning and imitation, while we teach analytical thinking and innovation, are debunked by quantitative and qualitative evidence.

Integrating Industry and University Viewpoints

In Table 1, we try to summarize the major issues that faced industry and universities over the years. Certainly, issues crossed these pigeonholes, but there are some general trends that got more attention in different periods. Over the years, there has been increasing communication and better understanding of perspectives, though this is not to claim that there has been, or will or even need be, total alignment. Table 1 is an attempt to summarize the evolution of issues informally – no claim is made that these perceptions of issues are generally endorsed.

Table 1: Evolution of Issues

Period	Industry	Universities
Mid-'80s	Cold War	Research vs. Instruction
Late 80s	Transition from mass-produced platforms to multiple projects and small production runs.	Increase design content in curriculum. Developing teaching metrics.
Early 90s	Total Quality Management. Team project environments.	Curricular reform initiatives; "Scholarship Redefined". Experiential learning. Experiments with new types of curricula.
Mid'90s	Gulf War 1. Market responsiveness, Production efficiency. Workforce fluctuation. Internet revolution.	Internet revolution. Integration of pedagogy research into university instruction.
Late '90s.	Dotcom boom. Worker shortage. Global competition starts.	System lifecycle simulation. Systems design curricula.

Early 00s	Recession. Terrorism & security issues. War economy. Drop in global demand. Loss of corporate memory.	Cross-disciplinary research. Emphasis on nano-systems, biotechnology. Undergraduate research participation. New ABET criteria focus on self-assessment.
Mid 00s	Cost-cutting; stiff global competition. Making money on R&D; small-group environments. Knowledge retention & transfer.	Distance learning. Questions about role of US education system. Assessment tools and practices.
2010s?	Large-scale distributed projects. LSI. Outsourcing design as well as production.	More choice in curricula. Diverse tracks and career choices. Need for substantial "societal" issue experience in engineering education.

The Boeing Welliver program, over the years, has been very effective in bridging major disagreements and building the confidence needed to institute effective and well-focused changes. We surveyed the "Welliver Alumni" (107 to-date) with 5 questions, shown at left. The responses are discussed below. First, some general observations from the responses.

Questions e-mailed to the Alumni of the Welliver Summer Faculty Fellowship program, January 2005.
1.How has WFSF influenced your relations with industry?
2.How has WFSF influenced the curriculum?
3.How has WFSF influenced your personal philosophy as educator?
4.What do you see as the top 3 issues for the future of engineering education today?
5. Are these the right questions? If not, please suggest the right questions.

How has WFSF influenced your relations with industry?
Better appreciation of how industry operates, and what is valued there. Ongoing interactions with Boeing. Enhanced understanding and credibility in dealing with other companies. Better understanding of how to frame research issues.

How has WFSF influenced the curriculum?
Creation of "Systems Engineering" courses and even entire curricula. Incorporation of "lean" ideas, "practical information", communication exercises, schedule and cost concerns and case studies into courses. Multidisciplinary team projects. Ideas from Integrated Product Teams. Increased interest in design. Lower-division introduction courses for perspective. Expanded elective choices. Reinforcement of ideas.

- The Welliver program focused on individual teaching faculty, rather than administrators, as ambassadors of change.
- It impressed faculty with its depth and breadth of corporate commitment. The opportunity to discuss issues with senior corporate talent was valued.
- The intensity and breadth of the 8-week individual experience, as well as "learning through colleagues' eyes" that came from comparing notes with the team, enabled a deeply impressive experience.
- Curiosity about the approaches taken by one's teammates, given the same problem definition and similar constraints, turned into strong friendships. That there was no real call for "competition" beyond the imperative of contributing one's best as a team member, is an extremely important facilitator of this experience
- It focused on the most important aspect of the teacher's profession – deciding how and what to teach their students, providing expert support in a team setting.
- Beyond this support, it left the freedom to plan and implement in the hands of the teacher, without pressure for short-term demonstrations.
- It continued to articulate a consistent message for a decade.

WFSF influence on personal philosophy as educator
Appreciation for how large projects come together for a single end product. Appreciation of System Engineering. Discussions with senior faculty. Overview of how different personalities fit into a modern engineering company. Reinforced importance of self-education skills. Far more acceptance of 'soft issues'. Reinforced commitment to undergraduate teaching. Awareness of why engineers need many types of expertise such as history, economics and politics. Need to pay more attention to fundamentals in the first 3 years of the undergraduate curriculum, and use the final years to transition to industry.

Top 3 issues for the future of engineering education:
Educating for innovation. Regaining pre-eminence in innovation and analytical thinking, with mathematical skills. Balancing soft skills vs. basics. Relevance of Bachelors' degree vs. Masters level first professional degree. Competing with law, medicine and business for the best students, and creating a welcoming environment for underrepresented groups. Finding resources for hands-on experiences; allowing undergraduates to reach their true potential to contribute to research / design projects. Adapting the curriculum to change. Anticipating technological advances. Developing interdisciplinary programs.

Program expectations and modes of involvement varied widely, driven by individual preferences, security / program constraints and the mentors' schedules and preferences. The common feature appeared to be that everyone had a huge volume of experience and accumulated project ideas to pursue. A search of the internet shows that faculty members are proud of being selected for any of the Boeing awards. An important difference in this program is the explicit expectation that participation in the Welliver program must have some lasting impact on academic programs, driven by faculty initiative. Some examples:

- Campus seminar upon return[11]
- ASEE papers[12,13,14,15] and IUGREEE presentation(s)[9].
- Curricular changes at all levels, specifically increasing "relevant examples" in courses, and incorporation of teamwork experiences.
- Ethics Case Studies[16].

A View Towards the Future

Clearly, the Welliver program has built enough bridges between industry and academia to move on to the next level in collaboration. We see opportunities for close synergy between industry and academia to deal with some of the very large opportunities that arise from the new emphases on globalization and large-system design. Universities are well-poised to take on the most risky parts of cross-disciplinary concept development, while industry can provide the relevance and some of the tools needed for such efforts. Closer involvement of faculty and industry experts who understand each other, will open the way to tailor effective joint programs, with students as the focal points.

An initial cut at the strategies for future engineering education is summarized below, incorporating some of the best practices from academia into evolving industry needs. A high quality undergraduate university program should address the following "basics":
• Demonstrate that engineering is practiced within a much broader societal context – not as an end in itself.
• Teach students how to learn - and make it clear that it is both a life-long pleasure and necessity.

• Develop a fundamental understanding of the unity of the fundamental tools and concepts needed for engineering practice (rather than providing them a vast bag of tricks for solving selected problems). These basic fundamentals include:

 – Mathematics
 – Information technology
 – Science, including the "engineering sciences"
 – Design and manufacturing (design-build-test projects)
 – Economics and business practices
 – Communication skills (written, oral, graphic and listening)

• Emphasize "design" (Creative thinking and open-ended problem solving in the most general sense) and its close connection with manufacturing (i.e. "If you can't build it, you can't use or sell it".)
• Show students how to get information and how to deal effectively with too much of it (i.e. emphasize critical thinking and evaluation skills)
• Emphasize teamwork (not merely "group work") and communication skills
• Emphasize the "Why" and "What" of theory, and how these basics are then applied in practice. The "How" in applications can then be further enriched by experience and subsequent training.

The relative importance of the above items should be a focus of discussion. For instance, if industry values the basic fundamentals, as is evident from the placement of that item on the list, that fact must be emphasized, so that the more "modern" items do not displace this from the university's list of priorities. These ideas are summarized in Figure 3, but we note that the same engineer need not fit all the different career choices.

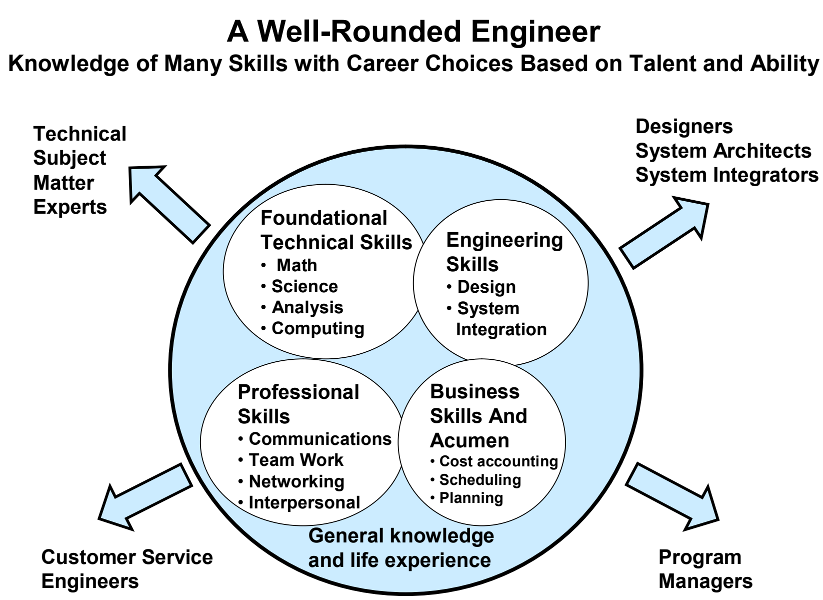

Figure 3. The Well-Rounded Engineer of the 21st Century

Concluding Remarks

US industry is moving towards large computerized models, capable of simulating, analyzing and optimizing very complex, large systems. The issues faced by industry and academia have not disappeared, nor have the constraints become any softer. However, successful experiments around the nation have explored how to solve many of the cited problems. There has been a major increase in variety and diversity of engineering education programs as well as careers. Many of the new careers are not "pure" engineering, but span fields involving much more social contact. The multitude of issues and technical skills seen in any development project require "soft skills" in engineering graduates. However, understanding the fundamentals and technical competence are paramount in new graduates. Industry-academia interactions are crucial to fully capture and disseminate the best practices, and exploit what students learn to a much greater extent in the workplace. The key to this is through university relations programs where faculty and industry engineers interact directly as well as through students. Boeing has invested a great deal in bringing about the changes that have occurred in the past 15 years – and the Welliver program is a particularly effective example. Future effort must build on this success.

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Appendix
Excerpts from Survey Responses

1.How has WFSF influenced your relations with industry?

"More accurate estimate of the status of Boeing as a multi-faceted large corporation"
"The complexity that exists in many issues addressed in the industry…Changed my view of how research problems in academia ought to be viewed, starting with asking probably the most fundamental question."
"..Industry relations was already a large part of my job…while at Boeing I was working with a Director, so I got to see management from the industry perspective."
"Made me more aware of what The Boeing Company is and what it needs to see in our graduates. However, it also taught me that industry needs are not as coherent as one would like to believe."
"Grants (from other than Boeing) have been awarded to support multidisciplinary design projects and workshops"
"Helped clarify the differences in the research methodology, approach, and goals that industry researchers pursue."
"Much more in tune with our .. students .. after they graduate.. not hesitant to call them ..to discuss something."
"All successful engineers were knowledgeable.. , excellent communicators and team players."
"Collaboration with Boeing to support a teaching/research endeavor I am conducting on my campus."
"Boeing engineers (WFSF contacts) have supported the senior aircraft design courses I teach;
"Directly led to the "system of systems" signature area that has become part of engineering at Purdue"
"Did not influence much my relations with industry"
"Allowed me to develop new contacts and to establish new directions for my own scholarship."
"Met many people that are good industry contacts to have."
"Provided substantial insight about and appreciation of how industry thinks and operates"
"Better context for understanding manufacturing and the integration of IT in a variety of companies"
"Understood qualifications and preparations for students to excel in an industrial environment."
"Improved understanding of industry needs and constraints... industry linkage research grant.."
"Industry was more receptive of my status of an 'Academician' because of my WFSF experience"
"Met many people... learned ..how the company operates and what kind of work environment my students will find when they get there. I will likely have a positive image of Boeing for a very long time.."
"Changed my view of industry: they are not philantropic organizations. They have to make money, they must solve problems that stand in the way right away. Trying to understand the fundametals is .. a luxury"
"Formed a collaboration with Boeing to support a teaching/research endeavor I am conducting on my campus."

2. How has WFSF influenced the curriculum?
"In large classes, I choose a team of 4 students and sometimes 5, and I do so randomly. I tell them the ultimate objective is to capitalize on their strengths to compile a compelling project report."
"Engineers as design review panelists for the capstone design."
"I have started a new aircraft design course with particular emphasis on aero-structural integration."
"I use numerous examples from my experience in the classroom."
"I went in with a mission to upload information to make my classes better, and I certainly got it."
"Guest lecturers from industry motivate topics that are important, but not so obvious to undergraduate students."
"I have since paid great attention to training the communication skills of students, such as abilities to express main ideas in a short time frame, to ask the right questions, (to make) oral presentations, to listen, and to write clearly."
"I have developed several case-studies based on my Boeing experience and contacts which I use in my classes."
"We are looking into creating a 'systems engineering' course"
"Participation in the WFSF program only reaffirmed my view that I was doing the right things in the classroom."
"I was delighted to be part of the IPT process that Boeing was using for its product line development."
"I became active in the design side of our existing curriculum."

3. How has WFSF influenced the personal philosophy as educator?

"To sum up, there is not a single person that knows everything about an aircraft, yet the distributed requisite knowledge is brought together and 'assembled' in harmony that makes metal fly. It is nothing short of a miracle."
"Made some changes, most notably with my attitude toward systems engineering."
"The program is successful when you get to sit around and talk engineering education with experienced professors."

"Where possible, we place students in industry co-op arrangements for their final year thesis projects."
"More aware of the importance of cost in engineering decisions, and also the paramount importance of ethics."
"WFSF provides a very nice and a very broad overview of a modern engineering company and how different types of personalities with engineering backgrounds and training fit into it."
"While preserving the need for analytically rigorous teaching, teach students the topics that they can benefit the most from applying in the industry upon graduation."
"Reinforced in me the need to nurture the ability to self-educate among the students. I believe that ironically, this is an area in which large research universities accidentally succeed better than smaller programs."
"Far more accepting of imparting training on 'soft issues' such as leadership, value of collaborative partnerships, sensitivity to others when working in teams, etc. which were not part of my vernacular before this experience."
"A profound shift occurred. I became much more committed to undergraduate education."
"I don't believe I would have read, thought about, talked about and written about education as I have done since."
"Became more aware of the many types of expertise an engineer needs - history, economics and politics."
"We must pay more attention to the fundamentals in the first 3 years and use the final year to transition the student from the classroom to industry. The industry then takes on the task of training the graduate."

4. What do you see as the top 3 issues for the future of engineering education today?

"Balancing soft skills vs. basics; continuous improvement; student pipeline management vs. varying demand."
"Ethics and assumption of personal responsibility."
"Establish a path to a master's level professional degree; make ABET understand that the concept of process improvement applies also to them; expose liberal arts students to engineering, and engineering thinking."
"Relevance of (bachelor's) degree to industry needs; more uniform improvement in communication skills; push to create the environment and get more acceptance and better utilization of undergrads in research programs."
"Curriculum/program management as "technology" continues to expand; attracting more women and minorities to engineering; managing the balance between "good" teaching and research demands during declining state support."
"Masters as first professional degree; enrollment; curriculum revolution."
"Enough resources to continually adapt the curriculum to changing technology."
"A solid training in basic science, the importance of honesty and tolerance, and the practical environment."
"Making technological progress synonymous with social progress, world-wide. Interdisciplinary collaboration."
"Fitting expanding knowledge into shorter curriculum. Finding the resources for hands-on experience. Attracting top talent to engineering schools in competition with law, business, and medicine."
"Teach how to think and solve new and different problems they may encounter."
"Teach to where we will be in technology in 2-5 years. Industry-relevant topics. Effective communication."
"How to evolve to fit the needs of a rapidly changing workspace while maintaining the strong emphasis on engineering science fundamentals. How to prepare a subset of our engineering population to become global engineering. How are we going to address the next evolution of industry."
"Industrial competitiveness. Revamp the accreditation process – note declining PE fundamentals exam scores under present ABET criteria. Meaningful dialogue on the proper content of engineering education."
"Ensuring strong K-12 education that supports a pipeline of students with interest in the STEM curricula."
"Recognize the importance of teaching and learning styles. Holding the interest of the brightest students. Serious challenge that we face to our decades-long position of leadership in science and technology."
"Training engineers who can *innovate*, as opposed to rote analysis. Ability to devote the proper attention to undergraduate education. Making engineering a welcoming discipline to underrepresented groups, such as women."
"Engineering education for sustainable development. Shift the paradigm towards addressing the common good for the global community, away from regional considerations."
"Reward system at universities is in direct opposition to industry needs– and has propagated to most institutions."
"Lack of resources; high cost of education that is preventing some good students from getting education; the continuous struggle with increasing the diversity of the student body."
"Introduce business sense. Develop cooperation skills. Holistic approach towards corporate engineering work."
"Making room for fast-changing technology. Develop interdisciplinary programs while keeping accreditation."
"We have almost lost analytic thinking. Basic mathematics skills are about to become extinct. Since mathematics is the language of science, we are fast losing our ability to teach science."

BIOGRAPHIES

Dr. John H. McMasters joined Boeing Commercial Airplanes in 1976 as a research aerodynamicist. He is currently a program manager for the Ed Wells Initiative, a joint program between Boeing and the Society of Professional Engineering Employees. He has also served since 1990 as an Affiliate Professor in the Department of Aeronautics and Astronautics at the University of Washington in Seattle He has been a member since 1994 of the Boeing University Relations Process Council and was one of the architects of the Boeing initiated Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREEE). An Associate Fellow of the American Institute of Aeronautics and Astronautics, he twice served as an AIAA Distinguished Lecturer - from 1992-94 and again in 2002-05. He was selected in 2004 to be the 29th SAE/AIAA Littlewood Memorial Lecturer, and has been selected as a Sigma Xi Distinguished Lecturer for 2005-07. Dr. McMasters hold B.S. (1961) and M.S. (1962) degrees from the University of Colorado at Boulder and a Ph.D. (1975) from Purdue University, all in Aeronautical Engineering.

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