The Fraying Web of Life and Our Future Engineers

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ABSTRACT

Evidence abounds that we are reaching the carrying capacity of the earth – engaging in deficit spending. The amount of crops, animals, and other biomatter we extract from the earth each year exceeds what the earth can replace by an estimated 20%. Additionally, signs of climate change are precursors of things to come. Global industrialization and the new technologies of the 20th century have helped to stretch the capacities of our finite natural system to precarious levels. Taken together, this evidence reflects a fraying web of life. Sustainable development and natural capitalism work to reverse these trends, however, we are often still wedded to the notion that environmental conservation and economic development are the 'players' in a zero-sum game. Engineering and its technological derivatives can also help remedy the problem.

The well being of future generations will depend to a large extent on how we educate our future engineers. These engineers will be a new breed – developing and using sustainable technology, benign manufacturing processes and an expanded array of environmental assessment tools that will simultaneously support and maintain healthy economies and a healthy environment. The importance of environment and sustainable development considerations, the need for their widespread inclusion in engineering education, the impediments to change, and the important role played by ABET will be presented.

I. INTRODUCTION

This address had its genesis at the International Engineering Consortium Executive ComForum 2000 where a fellow Consortium Director, Chris Earnshaw, asked me to supply him with several "white papers." These early 1990s papers supported the Consortium's effort to catalyze transformational change in the areas of communications infrastructure, education, and the environment. The letter covering the transmission of the papers became the basis for a paper entitled: "*Educational and Environmental Initiatives: Some Recollections, Observations, and Recommendations*," that was first published by the Consortium for distribution at the Spring 2001 National Electrical Engineering Department Heads Association Meeting. The paper received widespread distribution, generated useful feedback, and, via the National Science Foundation's Janet Rutledge, led to an invitation to deliver a keynote address at the 2001 Virginia Tech and EPA sponsored Green Engineering Conference.

Following that conference, work began on a proposal to close the environmental literacy gap that exists in most of our nation's engineering programs. This proposal effort provided valuable insights and eventually led to a renewed campaign for engineering education reform and an attempt to answer three

Quantum Sensing and Nanophotonic Devices, edited by Manijeh Razeghi,
Gail J. Brown, Proc. of SPIE Vol. 5359 (SPIE, Bellingham, WA, 2004)
0277-786X/04/$15 · doi: 10.1117/12.547688

questions that seem critical for understanding why engineering education reform is needed and needed now.

These questions are:

1. Why is the large change such as that implied by "engineering education reform" needed?
2. Why cannot incremental change make the changes needed on an appropriate time scale?
3. Why do we need to recognize leadership and systemic change in engineering education now?

The answers to these questions appear elusive without some focus to help those not already committed to understand the urgency and move toward commitment. So, let me offer a few summary answers to these questions to preface my talk.

First, engineering graduates need to be significantly better prepared for the 21st-century engineering workplace. Although the (now) traditional engineering education offered at most of our engineering schools provides a good education about the technical aspects of engineering, other areas such as communication competence, ethics and professionalism, sustainable development and the environment, working in teams, the current approach to quality, focus on customer needs, "business" practices, and other non-technical areas seem to receive little or no attention in many engineering curricula. Therefore, many engineering graduates do not have the breadth of jobs available to them they could have. Qualified engineering students at the freshman and sophomore level fail to see engineering as a profession that helps people – one that focuses on meeting people's needs; and/or they find the learning environment unsatisfactory. They then transfer to another field of study.

Second, the changes needed are broad in scope – beyond just changing a few courses. Many of these changes must be made at the same time. Engineering programs need to attract and retain more of the "best and brightest" students on the campus. To make these changes, faculties need to change their view of what the curriculum should be like.

Third, those taking leadership roles in engineering education reform will need to devote a significant portion of their time for an extended period of time to implement the engineering education reforms needed. We also need to involve some of the best minds among our faculties. Without recognition and reward for their efforts, these individuals likely will choose other places to put their efforts.

II. SOME HISTORICAL PERSPECTIVES

A myriad of articles, papers, books, workshop and conference proceedings have made a compelling case for systemic engineering education reform. Among these are the 1994 Joint Project Report on *Engineering Education for a Changing World* by the Engineering Deans Council and Corporate Roundtable of the American Society for Engineering Education the 1995 Report by the Board on Engineering Education of the National Research Council, and the recent call for change by the National Academy of Engineering leadership, President, William F. Wulf and Chairman, George M. C. Fisher.

Although there has been progress, resistance to change continues unabated, in spite of the numerous calls for action, increasing competition from alternate service providers, as well as student-pipeline and job-security issues. A survey conducted by the Boyer Commission indicated that research universities have invested considerable effort in improving undergraduate education in recent years; "*but it also suggests that most efforts have been directed at the best students; the challenge for almost all is to reach a broader spectrum of students*."

The introduction of new, outcomes-based accreditation criteria, Engineering Criteria 2000 (EC 2000) by ABET, the Accreditation Board for Engineering and Technology, and the funding of a number of programs related to systemic engineering education reform by the National Science Foundation in the early 1990s, are seminal events on the path to a new paradigm for engineering education. The 1998 Engineering Foundation Conference (EFC'98) provided further impetus. Co-chair, Edward W. Ernst, University of South Carolina, reminded the participants that intense discussions beginning in the late 1980s, coupled with several conferences, workshops and studies "produced a consensus about what engineering education should be – what the stakeholders expect in the content of the curriculum, innovative approaches to teaching, and involvement of students. Achieving the change needed in engineering programs across the country has become the current barrier that must be surmounted for engineering education to realize the new paradigm for engineering education and to serve the stakeholders even better."

Achieving change via engineering education reform presents a formidable challenge given academe's bias toward preservation of the status quo where publications and research funding drive rewards and recognition. It is part of the overarching challenge of change, faced by universities and colleges throughout our nation, as described by Duderstadt in his comprehensive analysis of the issues and the need for new paradigms. This is a complex age of rapid change where different points of view and conflicting interests characterize the stakeholders who often resemble disconnected parties.

Recent times have seen no clear path forward and an apparent absence of focused, action-oriented leadership. Also, the engineering education reform movement has been clouded by mixed, and sometimes disquieting, messages of equivocation that could be interpreted as disclaimers or "escape clauses" – saying, in effect, that there need be no sense of urgency about engineering education reform. So systemic change continues to proceed at geologic speed despite ardent efforts during the mid-1990s. Why might this be so and what might be done to accelerate the pace of change? The answers to these questions are complex and institution dependent, not amenable to a one-size-fits-all resolution.

III. AN ENVIRONMENTAL LITERACY GAP

Going back to the future, it was evident to the ABET's first Industry Advisory Council that sustainable development was becoming a dominant economic, environmental, and social issue of the 21st century, and that a fundamental change in engineering education was required to help the next generation of engineers learn to design for sustainable development and long-range competitiveness. We called upon ABET to bring about a major paradigm shift in engineering education. Among other things, the we asked that emphasis be placed on teamwork and an interdisciplinary understanding of the societal, ecological, financial, national, and global impacts of engineering. We also recommended a set of

Accreditation Process Principles and Concepts & Supporting Strategies that later helped form the basis for ABET Engineering Criteria 2000 (ABET EC 2000): Criterion 3 Programs Outcomes and Assessment.

The *Accreditation Process Principles* called for the "understanding of and work toward sustainable development, safety and environmental impact." We also asked that engineering programs seek to provide their graduates with a combination of skills, attributes, and characteristics among which were: "A holistic approach to achieve solutions to engineering challenges by integrating the elements of general education including human needs, culture, history and tradition, sociology, politics and government, economics and the environment." In the process of balancing specific guidance against flexibility of choice by engineering programs, the wording of the *Accreditation Process Principles* relative to environmental considerations was subsequently generalized. Thus, the present criteria do not reflect the emphasis that we originally placed on these considerations.

Emphasis on the environment and sustainable development was considered one of our more important recommendations and was promulgated as such at ABET and American Society for Engineering Education conferences.

Today, much of environmental engineering education, meaning environmental topics and considerations, are to be found mostly in civil, environmental, and/or chemical engineering programs. This creates a two-part problem in engineering education. First, environmental design constraints and opportunities should permeate all engineering disciplines, as environmental factors need to be considered at the beginning of every engineering problem; and second, as good as ABET EC 2000 is, its criteria are open to an interpretation that can permit an environmental literacy gap to exist in our engineering programs and disciplines.

However, the beauty of the ABET engineering criteria structure is that the environmental literacy gap can be closed by adding the word "environmental" to Criterion 3(f), rewording Criterion 3(h), or by requiring, in Criterion 4, that environmental impact is considered in the student's capstone project. Since ABET engineering criteria are focused on student outcomes, new courses would not be mandated. The programs would be free to develop their own innovative ways to guide all engineering students to an understanding that environmental factors are an element of "best engineering practice;" and, that this understanding will be an important outcome of their engineering education.

An effort to close the environmental-literacy gap was initiated early in 2002. No matter how important, the infusion of environment into the ABET engineering criteria was not expected to be easy. The National Council for Science and the Environment (NCSE), Northwestern University, and Virginia Tech endorsed a related proposal while personal endorsements and commentaries came from academe and industry. Here for example is a comment by Northwestern Professor Manijeh Razeghi:

"Environmental awareness is a necessary part of all education, not just for engineers. Within the engineering sphere, however, we must do our best to help students understand the cause and effect of their decisions relative to the environment. Changing the ABET Engineering criteria to include "environmental responsibilities" should be enacted immediately. Environmental responsibility should become a core part of all engineering classes. New classes are not needed, but current professors need to be educated on how to integrate environmental impact into their classes. Design projects can be geared to this as well, when applicable, which will get students thinking creatively about these issues outside of class. I endorse this initiative as a positive step toward environmental literacy."

The proposal is still in the arduous process of ABET review, endorsed in principle, by the Accreditation Policy Council of the IEEE Educational Activities Board. But here is some good news: the ABET Engineering Criteria have been marked up with revisions that were accepted by the ABET Board of Directors on first reading at their meeting on November 1, 2003. The revisions were those proposed by the IEEE on top of some minor changes and definition insertions that were approved on second reading at the same time.

We can all hope that the revised Engineering Criteria will be approved on second reading at the Board's fall meeting in 2004 and be applicable for visits commencing in fall 2005. Engineering programs must then demonstrate that their students attain an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, as well as demonstrate the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

IV. THE IMPORTANCE OF SUSTAINABLE DEVELOPMENT

But why all this emphasis on environmental considerations and sustainable development? Here's why. Evidence abounds that we are reaching the carrying capacity of the earth – engaging in deficit spending if you will. The amount of crops, animals, and other biomatter we extract from the earth each year exceeds what the earth can replace by an estimated 20%. Additionally, signs of climate change are precursors of things to come. What's more, global industrialization and the new technologies of the 20th century have helped to stretch the capacities of our finite natural system to precarious levels. Taken together, this evidence reflects a fraying web of life.

Numerous organizations and efforts have cited the importance of sustainable development. For example, the National Science Board began its report, *Environmental Science and Engineering for the 21st Century*, with the statement, "Within the broad portfolio of science and engineering for the new century, the environment is emerging as a vigorous, essential, and central focus… The environment is no longer simply a background against which research is conducted, but rather the prime target for increased understanding."

The Board recommended that "Environmental research, education, and scientific assessment should be one of NSF's highest priorities;" and called on the NSF to "encourage proposals that capitalize on student interest in environmental areas while supporting significantly more environmental education efforts through informal vehicles."

Over the past fourteen years, the National Academy of Engineering, through its program on Technology and Sustainable Development, has conducted a series of industrial ecology workshops and related studies with numerous publications – all with the aim of illuminating the relationship between technology, economic growth, and the environment. Furthermore, during a May 2000, Executive Summit at the World Telecommunications Congress, thirteen of the world's leading telecommunications companies pledged to work together to promote a range of measures designed to realize the positive impact of the communications industry on the global environment and on sustainable development. The Congress organizer, Chris Earnshaw from BT, saw a virtuous circle between the success of his corporation's business and sustainable business practice.

The 2001 *BusinessWeek 50* contained an interview with a *Master of Innovation* in energy efficiency, Amory B. Lovins, CEO of Research at the Rocky Mountain Institute. Lovins and his co-authors expand on the subject in *Natural* In their book, they claim that most businesses still operate according to a worldview that has not changed since the start of the Industrial Revolution when natural resources were abundant and labor was the limiting factor of production. The authors go on to provide a number of case studies and explain how the world is on the verge of a new industrial revolution wherein business and environmental interests will increasingly overlap, and in which companies can improve their bottom lines while helping to solve environmental problems and foster the innovation that drives future improvement. These, and other efforts, provide a wake-up call for our engineering programs to guide students to a basic understanding of environmental impact on design.

So we see that engineering and its technological derivatives can help remedy environmentally related problems. Although sustainable development and natural capitalism can work to reverse ominous trends, we are often still wedded to the notion that environmental conservation and economic development are the 'players' in a zero-sum game. So the well being of future generations will depend to a large extent on how we educate our future engineers … engineers who can transcend this false notion. These engineers will be a new breed - developing and using sustainable technology, benign manufacturing processes and an expanded array of environmental assessment tools that will simultaneously support and maintain healthy economies and a healthy environment.

V. THE IMPEDIMENTS TO CHANGE

The examples mentioned above present many openings for dialogue and debate on both the extent and the manner in which the concepts of sustainable development and sustainable business practice can be integrated into the curriculum of our engineering programs. Such integration can best be described as disruptive educational "product" innovation. Engineering education innovators are thus faced with the innovator's dilemma – aptly described by Clayton Christensen. So what's the dilemma? Simply stated, it is the fact that educational products in this vital area do not represent the coin of today's academic realm. Put another way, they do not fit the present-day rewards and recognition systems operative at most of our engineering programs; further, there has been strong resistance to embedding additional requirements in the ABET criteria.

Views similar to the above have been expressed by Suren Erkman and John Ehrenfeld. In a historical view of industrial ecology, Erkman states: "there is a need for integrating industrial ecology into new management practices. Education of engineers, economists, managers and natural scientists becomes crucial, in order to deal with a serious cultural problem: ecologists usually don't know about the industrial system. On the other hand, engineers, and people from industry in general, have a very naïve view of nature and are very defiant against ecologists and ignorant about scientific ecology." MIT's Ehrenfeld discusses the role of universities in industrial ecology and states: "the university can and must play a central role in developing the concept of industrial ecology and institutionalizing its practice." According to Ehrenfeld, to do this, the universities must overcome strong disciplinary barriers, jealousies, and their own political dynamics, as well as enter into a broad discourse among all the players. He also sees the need to reconstruct the disciplines in a way that mimics the seamless web of the very world we are attempting to understand.

These views may appear to be a bit harsh, but they are not all that new. In a 1938 lecture, given to the College of Engineering at the University of Wisconsin, Aldo Leopold, a foremost conservationist and environmental scholar, pointed out the adverse ecological consequences of civil engineering. Of particular interest are his comments: "Every professional man must, within limits, execute the jobs people are willing to pay for. But every profession in the long run writes its own ticket. It does so through the emergence of leaders who can afford to be skeptical out loud and in public – professors, for example. What I here decry is not so much the prevalence of public error in the use of engineering tools as the scarcity of engineering criticism of such misuse. Perhaps that criticism exists in camera, but it does not reach the interested layman." Leopold felt that an understanding of ecology "is by no means co-extensive with 'education'; in fact, much higher education seems deliberately to avoid ecological concepts."

VI. OUTLOOK FOR THE FUTURE

Experience teaches that change must sometimes come from outside. For example, Karl Martersteck, a former vice president at AT&T Bell Laboratories and former president and CEO of ArrayComm, pointed out that: "environmental concerns are not likely to find a place in most engineering curricula without a forcing function such as the ABET criteria." Some five years ago, at the 1998 Engineering Foundation Conference – *Realizing the New Paradigm for Engineering* – ABET EC 2000 was looked to as a mechanism that could be used to drive as well as enable change and it is now likely to do just that.

A sign of progress is beginning of work by faculty in various disciplines to resolve the problem of how and what to include in an already full curriculum. For example, a paper will be presented by Linda Vanasupa, Materials Engineering Department, California Polytechnic State University, at the Material Research Society's Annual Conference in April 2004. Linda is the chair of the Academic Affairs Committee of the Materials Science and Engineering Society. The paper, "Curricula for a Sustainable Future: A proposal for integrating environmental concepts into our curricula," will address the challenge of adjusting materials science and engineering (MSE) curricula – Linda and I will propose a path for integrating environmental and sustainability concepts within the framework of the performance-structure-processing-properties paradigm as well as suggest learning outcomes for each year of the MSE curriculum and offer examples.

Over time, it is expected that commonplace practice of sustainable development and business practice will evolve over time, either by choice or by catastrophe. The key to evolution by choice is expected to be the growing awareness by the financial and investment communities of the intrinsic value of ecoefficiency – maximum long-term economic gain and minimum overall environmental impact – as defined by the World Business Council on Sustainable Development – and "blueprinted" in *Natural Capitalism*. Businesses will then exert an ever-increasing demand for engineering graduates conversant with environmental issues and economics, and, most importantly, engineers skilled in systems thinking and in related ecoefficient design and manufacturing practices. In turn, this change will give birth to a new paradigm in engineering education – environmentally-smart, life-cycle design for competitive advantage.

Green Engineering Programs are a good beginning – so too, are Engineering Forums such as the American Society for Engineering Education Engineers Forum for Sustainable Development and the Institution of Electrical Engineers Professional Network on Engineering for a Sustainable Future Noteworthy, is the work of the National Council for Science and the Environment to bring about the full implementation of the recommendations set forth in the NSF's report on its future role in environmental science and engineering. For example, its Environmental Deans and Directors Council has just marked a successful first year in its mission to improve the quality of environmental programs on this nation's campuses. Encouraging, as well, is the work done by the Technical Activities Committees of the various Engineering Societies, the Association of Environmental Engineering and Science Professors and the American Academy of Environmental Engineers. All of these have the opportunity and the wherewithal to develop traction to help propel the engineering community along the arduous path to commonplace industrial and academic practice of sustainable and environmentally conscious engineering.

VII. CONCLUDING REMARKS

As we continue to move into the 21st century, helping academia understand the escalating changes in industry, and the relationship of the changes to the concepts of sustainable development and sustainable business practice, will present a major challenge. Significant advances in industry's supporting technologies and services, together with their business and environmental implications make academia's learning needs substantial. ABET, can play a vital role in this area. Nevertheless, what appears to be common sense has yet to become common practice. Not until we see most of our engineering programs placing a high value on these concepts, as evidenced by incorporation in the program's mainstream value network, will we know that we have progressed beyond the early adopter phase of concept diffusion. We will then witness most of our engineering programs operating to bring balanced perspectives to engineering via the ecoefficiency paradigm – environmentally smart, life-cycle design for competitive advantage. Today, it is a paradigm that is making good progress.

Let me now begin the ending of this talk with a quote from the Club of Rome's Aurelio Peccei and Alexander King. It is a quote that I used when writing the opening to *Creating Our Common Future* some twelve years ago – "If the ways of God are inscrutable, the path of man has become incomprehensible. Modern man, despite the wonderful body of knowledge and information that he has accumulated and the means to apply it, appears to be muddling ahead as if he were blind or drugged, staggering from one crisis to another."

In this light, reflection on the events of the past twelve years, still leads me to believe that the clear and present danger faced by the world in general – and, the United States in particular – has to do with two polarities: the ecological polarity between human activities and the life-sustaining capacity of the Earth and the polarity between the haves and have-nots.

I believe that conservation is much more than a "personal virtue" and that sustainable development is an imperative…not an option or a utopian dream. I believe that sustainable development will remain the dominant economic, environmental and social issue of the 21st Century, and that it will evolve either by choice or by catastrophe. I continue to believe that engineers, as problem formulators and solvers, should be at the center of the choice-related debates. All of this will require a fundamental redirection in Engineering Education – aimed at producing engineers who possess a sensitivity to the social, cultural, economic, and the industrial environment in which they work, as well as the competency to accept responsibility for effective societal leadership.

The formidable challenge to change in our engineering education system demands no less than a formidable and coordinated response as well as able and respected leadership. The National Academy of Engineering has the wherewithal and is well positioned to provide this response, as well as to provide requisite leadership by example. It would be a credit to the Academy, and a boon to engineering education reform, if it would work to help enable the widespread implementation of the changes needed in our engineering education system – helping to motivate and mobilize the stakeholders in engineering education to address the challenge to change. The stakeholders – academic administrators and faculty members, government policy makers and agency program managers, and professional society as well as industry leaders – should see this as clarion call to action on their parts as well. The education of this nation's future engineers deserves no less.