ENGINEERING EDUCATION REFORM: A Trilogy

ENVIRONMENTALLY SMART ENGINEERING EDUCATION: A Brief on a Paradigm in Progress

THE CHALLENGE TO CHANGE: On Realizing the New Paradigm for Engineering Education

ENGINEERING EDUCATION REFORM: A Path Forward

January 2003

Frank G. Splitt

McCormick Faculty Fellow
Northwestern University
McCormick School of Engineering and Applied Science

DEDICATION

This publication is dedicated to the memory of the late Arthur J. Schmitt, the inventive industrialist who founded the Amphenol Corporation in 1932 and the philanthropist who founded the Arthur J. Schmitt Foundation in 1941. Concerned that engineers were being too narrowly educated and that industrial leadership was going by default to those with backgrounds in general education, he became the educational innovator who founded the Fournier Institute of Technology in 1943. Mr. Schmitt's quest was for leadership. His aim was to provide effective industrial leadership via electrical engineers skilled not only in their profession, but in business administration and communications as well. His vehicle was education. Mr. Schmitt often paid tribute to America's engineering genius and cited the importance of engineers in America's future. He believed there was no field with richer rewards, none more intriguing, and none more important to the growth and defense of our nation. His mission continues through the work of the Arthur J. Schmitt Foundation.

Arthur J. Schmitt
(Photo courtesy of the Arthur J. Schmitt Foundation)

For more on Arthur J. Schmitt see: Schaefer, Arthur J., *Quest for Leadership: The Arthur J. Schmitt Story,* Cathedral Publishing, Chicago, IL.

CONTENTS

The International Engineering Consortium sponsored the publication of this trilogy as a public service to academia, government and industry. The Consortium is a nonprofit organization dedicated to catalyzing positive change in the information industry and university communities. It provides high-quality education for industry professionals, academics, and students. Among its initiatives are educational conferences, technology exhibitions, on-line educational programs, and the publication of research studies that focus on major issues and emerging technologies. More than 70 leading high-technology universities are currently affiliated with the Consortium. Industry is represented through the involvement of thousands of executives, managers, and professionals. For more information visit www.iec.org .

FOREWORD

In a changing environment and under pressure we do what we can to avoid being left behind or dealt out. We fall back where we can on the status quo to maintain our comfort zones. So it is with our professions and with undergraduate education reform.

Post-Sputnik, more money for research became available to academia than ever before. Universities adapted and evolved into today's research institutions. Faculty success is now judged by production of new knowledge, publication in the "right" journals, and procurement of outside funding. These research-related measures now dominate decisions about hiring, merit, promotion and tenure. Faculty members are subject matter experts as a matter of survival. The supporting infrastructure grew, too, and needs funding as well, so faculty and administrators have become fundraisers and managers. Without the (mostly) federal funds on which they now depend, some academic units could not meet current payrolls.

Many engineering faculty are buying out teaching time, setting their agendas to respond to granting agencies rather than to students and colleagues, and running near burnout. It can be so difficult to give time and energy to undergraduate curriculum development that too often faculty fall back on familiar material and ways of teaching. Declining enrollments are evidence that this is no longer working well. Student interest in engineering as a career is not being engaged as it once was.

Substantial mismatch exists between the interests and concerns of the MTV generation and those of faculty striving for success on the measures the university rewards. The current undergraduate student body differs in important ways from those of the past. Students have a sense of entitlement to a good grade despite a mediocre performance. They like to manipulate software, but are much less interested in learning the underlying principles. They use their hand-held calculators efficiently, but rarely get the physical picture well enough to recognize errors in the results – even when they grind out nonsense. The instructor is viewed skeptically for suggesting regrouping the symbols in an equation to look for simplifications in the calculation, or even just using approximations like canceling pi squared over 10. The art of the back-of-the-envelope calculation is virtually lost. It is a different world, and the system needs fixing at a time when the nation needs new engineering talent.

There has been progress in both curriculum content and pedagogy in a number of individual engineering programs, and there is evidence from the NSF Engineering Coalitions of increased student retention, faculty rejuvenation and some institutional sharing of successful new approaches. Many engineering programs are still providing undergraduates with Sputnik-era kinds of instruction, however. Too often we employ the teaching styles to which we ourselves once responded. Some of today's dedicated, but overburdened, faculty members invest considerable time and energy in undergraduate program reform as a labor of love and without much expectation of reward. They are virtually powerless to change the priorities and demands of their institutions, and they are only human.

Old ways do not prepare undergraduates well for the 21st Century marketplace, either. Strong messages from the employers of our undergraduates have been heard for some time. ABET responded to industry's warnings with its outcomes-based ABET EC 2000. No longer need a program count beans that fit outdated curricula. Rather, new criteria ask for evidence that the program meets the goals of its own curriculum design. This is an important step forward for undergraduate engineering education. NAE has responded with the prestigious new Gordon Prize for innovation in engineering education and, most recently, with the formation of a Center for the Advancement of Scholarship in Engineering Education that will seek to motivate continuous improvement in engineering education.

The author of these three papers, the trilogy, offers specific suggestions. In a true missionary spirit, he draws on extensive industrial experience, his participation in the early development of ABET EC 2000, and a substantial immersion in academe to provide his own noteworthy insights and a number of provocative ideas. Whether or not you agree with them, this interesting set of papers should be viewed as a valuable contribution to the literature on engineering education reform. It is worthy of serious attention and discussion by all stakeholders in engineering education.

Irene Peden
Professor Emerita, University of Washington

PREFACE

These papers had their genesis at the International Engineering Consortium (IEC) Executive ComForum 2000 where fellow IEC Director Chris Earnshaw asked me to supply him with several "white papers." These early 1990s papers supported the IEC'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 IEC for distribution at the Spring 2001 National Electrical Engineering Department Heads Association Meeting. The paper received widespread distribution, generated useful feedback, and, via the NSF's Janet Rutledge, led to an invitation to deliver a keynote address at the 2001 Virginia Tech and EPA sponsored Green Engineering Conference. Following the 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 questions that seem critical for understanding why engineering education reform is needed and needed now.

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 can be found in these papers, but perhaps without the focus needed 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 as a preface to the papers.

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, faculty 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.

These views and those expressed in all of the papers reflect an industry perspective. They are based on my fifty years of experience as an engineer – including forty years of workforce experience in the telecommunications industry spanning product design, R&D, and management. Industrial experience as an engineer-practitioner was complemented with service on several industry advisory boards – ranging from service at a community college and two research universities, to service on the ABET Industry Advisory Council and the Educational Activities Board of the Institute of Electrical and Electronic Engineers (IEEE). Close interaction with deans and faculty, on-campus and at several University-Industry Colloquia and other events, sponsored by the International Engineering Consortium, provided valuable insights and feedback as well. Dialogues with students during the course of campus visits and invited lectures influenced my perspectives.

Arthur J. Schmitt had a profound overall influence on my thinking, career, and direction in life via the educational experience he provided at the Fournier Institute of Technology. With reference to these papers, perhaps the strongest influence came from the research and commentaries surrounding a number of addresses – related to the future and to the changing needs of industry – given to engineering-school students, parents, faculty and administrators during the period, 1986-1993. The numerous papers and reports on engineering education referenced herein, also contributed to the shaping of my views, particularly those of Edward W. Ernst, Distinguished Professor Emeritus, University of South Carolina, and the late Ernest L. Boyer, Past President of the Carnegie Foundation for the Advancement of Teaching. However, in the end, the following opinions and views are entirely my own; and, as such, they do not carry or imply formal endorsement by any of my past or present institutional affiliations.

PART I
Environmentally Smart Engineering Education: A Brief on a Paradigm in Progress

ABSTRACT

Sustainable development has become the dominant economic, environmental, and social issue of the 21st century, yet its broad infusion within engineering education programs remains a challenge. This paper discusses the importance of environment and sustainable development considerations, the need for their widespread inclusion in engineering education, and the impediments to change. The roles of ABET and others in the evolution of these considerations in engineering education are presented; however, it is through the ABET engineering criteria that broad adoption of environment related considerations in engineering education will most likely occur. An effort to achieve this aim is described.

I. INTRODUCTION

Engineering education has undergone significant reform since the mid-1980s, with the environment and sustainable development emerging in the late 1980s as major issues not yet reflected in this reform. Speth and Smart said it well in 1990 [19], "*In survey after survey, people call for a better environment and improved economic conditions. These are not mutually exclusive goals. Rather, they are necessary and mutually supporting conditions… businessmen, environmentalists, and politicians must forego finger-pointing and join together and create a global program for sustainable development*." It was obvious then, that this issue was going to have a significant impact on industry and engineering education in the future.

At about the same time, during his term as the president of the Accreditation Board for Engineering and Technology (ABET), Ed Ernst initiated the formation process for an ABET Industry Advisory Council (IAC). It was his view that ABET was in need of more proactive involvement of industry leaders. He also saw ABET in a high-leverage position to affect change in engineering education since a major restructuring of the accreditation criteria and process would have significant long-term effects. The ABET IAC had its first meeting in May 1991, a time when President James Duderstadt of the University of Michigan, President Charles Vest of the Massachusetts Institute of Technology, and others, were calling for a fundamental change in the post-World War II model for engineering education. This was also the time when the National Science Foundation (NSF) was demonstrating increased interest in curricular innovation [18]. However, it was really the ABET efforts that provided a platform to implement major changes in engineering education as well as a venue for the broad introduction of environmental protection and sustainable development imperatives into engineering programs.

It was evident to the ABET IAC that sustainable development was becoming a dominant economic, environmental, and social issue of the 21st century [3][13], 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. This view was reflected in a letter sent to the ABET president, Al Kersich, by ABET IAC chairman, Mike Emery, that called upon ABET to bring about a major paradigm shift in engineering education [7]. Among other things, the ABET IAC asked that emphasis be placed on teamwork and an interdisciplinary understanding of the societal, ecological, financial, national, and global impacts of engineering. It 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 [8][24].

The *Accreditation Process Principles* called for the "*understanding of and work toward sustainable development,… safety and environmental impact*." 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, Criterion 3 presently does not reflect the emphasis that the ABET IAC *Accreditation Process Principles* placed on these considerations. The ABET IAC 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*." Emphasis on the environment and sustainable development was considered one of the ABET IAC's more important recommendations and was promulgated as such at ABET and American Society for Engineering Education (ASEE) conferences [21].

Looking back, it can be understood why Criterion 3 was generalized to the extent that it was. The burden of developing case studies and other mechanisms that enable student learning in the areas listed is exactly where it should be – on the engineering programs. Unfortunately, a significant opportunity for an appropriate level of guidance may have been lost in the process of getting to this end objective.

II. AN ENVIRONMENTAL LITERACY GAP

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.

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. However important, the infusion of environment into the ABET engineering criteria will not be easy.

An effort to close the environmental-literacy gap was initiated early this year. 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, see the Appendix and Reference [25]. The proposal is in the process of ABET review, endorsed in principle, by the Accreditation Policy Council of the IEEE Educational Activities Board.

A. The Importance of Sustainable Development

Numerous organizations and efforts have cited the importance of sustainable development. For example, the National Science Board (NSB) began its report, *Environmental Science and Engineering for the 21st Century* [14], 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 NSB 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 twelve years, the National Academy of Engineering (NAE), 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 [10] [11][26]. Further, during a May 2000, Executive Summit at the World Telecommunications Congress (WTC) organized by International Engineering Consortium (IEC)-Director Chris Earnshaw), 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. Earnshaw and BT see "a virtuous circle between the success of our business and sustainable business practice…" [5].

Finally, the 2001 BusinessWeek 50 (BW-50) contained an interview with a *BW-50 Master of Innovation* in energy efficiency [2], Amory B. Lovins, CEO (Research) at the Rocky Mountain Institute. Lovins and his co-authors expand on the subject in *Natural Capitalism* [12][27]. 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.

B. 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 [4]. The dilemma is that educational products in this vital area do not represent the coin of today's academic realm – simply put, they do not fit the present-day rewards and recognition systems operative at most of our engineering programs [20][25]; further, there is strong resistance to embedding additional requirements in the ABET criteria.

Views similar to the above have been expressed by Suren Erkman [9] and John Ehrenfeld [6]. In a historical view of industrial ecology [9], 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 [6] 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 [15], 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* [16]."

III. 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 [17][25]: "environmental concerns are not likely to find a place in most engineering curricula without a forcing function such as the ABET criteria." At the 1998 Engineering Foundation Conference (EFC'98) – *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 [1][22].

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 [23][28] – and "blueprinted" in *Natural Capitalism* [12]. 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 AAES/ASEE Engineers Forum for Sustainable Development and the Institution of Electrical Engineers (IEE) Professional Network on Engineering for a Sustainable Future Noteworthy, is the work of the NCSE 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 [14]. 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 (AEESP) and the American Academy of Environmental Engineers (AAEE). 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.

IV. CONCLUSION

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, acting in its consultative capacity, 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 remains a paradigm in progress.

ACKNOWLEDGMENTS

Over the years, many organizations and people contributed to the work described in this paper at different times and in a variety of ways. Ultimately, people, and not organizations, really helped to make things happen. My appreciation and thanks go to Bob Barnett, Wayne Bennett, Ted Bickart, Michael Bunch, John Birge, Dave Blockstein, Joe Bordogna, Steve Carr, Dick Carsello, Jerry Cohen, Elizabeth Coles, Mike Emery, Chris Earnshaw, John Ehrenfeld, Ed Ernst, Sam Florman, Bob Frosch, Jim Gibbons, Jack Gibbons, Mike Gorman, Mike Gregg, Abe Haddad, Martin Hellman, Hazel Henderson, Kristin Hill, Bob Janowiak, Ken Laker, Amory Lovins, Karl Martersteck, Jim McKelvey, Curt Meine, Art Moeller, John Pappas, Jim Plummer, Jim Poirot, John Prados, Manijeh Razeghi, Mike Sanio, Bill Schowalter, Tim Trick, Jim Vaughan, Julia Weertman, and Jim Wolter.

REFERENCES

1. Agogino, Alice M., Edited Transcripts of the Workshop Presentations, Proceedings of the 1998 Engineering Foundation Conference, New York, NY, June 3-6, 1998.
2. *Amory Lovins*, BusinessWeek 50, Masters of Innovation Section, Spring 2001.
3. Brewer, Garry D., *Business and the Environment: A Time for Creative and Constructive Coexistence*, The Twenty-fifth Annual William K. McInally Memorial Lecture, School of Business Administration, The University of Michigan, March 31, 1992.
4. Christensen, Clayton M., *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Harvard Business School Press, Boston, MA, 1997.
5. Earnshaw, Chris, *Digital Futures Report*, Digital Futures Conference, London, March 1, 2001.
6. Ehrenfeld, John R., *Industrial Ecology and Design for the Environment: The Role of Universities*, The Greening of Industrial Ecosystems, pp 228-240, National Academy Press, Washington, D.C., 1994.
7. Emery, Michael B., (*On Accreditation Process Principles and Concepts & Supporting Strategies*), Letter Correspondence to Albert T. Kersich, ABET President, Sept. 29, 1993.
8. Engineering Accreditation Commission, *Criteria for Accrediting Engineering Programs (Effective for* Evaluations During the 2001-2002 Accreditation Cycle), ABET, Baltimore, MD, Dec. 26, 2000.
9. Erkman, Suren, *Industrial Ecology: A Historical View*, Journal of Cleaner Production, January 1997.
10. Frosch, Robert A., et al, The Bridge, National Academy of Engineering, Vol. 23, No.2, Summer 1993.
11. Frosch, Robert A., et al, The Bridge, National Academy of Engineering, Vol. 29, No.1, Spring 1999.
12. Hawken, Paul, Lovins, Amory, and Lovins, L. Hunter, *Natural Capitalism: Creating the Next Industrial Revolution*, Rocky Mountain Institute, 1999.
13. Hatch, Henry J., *Accepting the Challenge of Sustainable Development*, The Bridge, National Academy of Engineering, Washington, DC, Spring 1992.
14. Kelly, Eamon M., et al, *Environmental Science and Engineering for the 21st Century: The Role of the National Science Foundation*, National Science Board and National Science Foundation, NSB 00-22, Arlington, VA, February 2000.

15. Leopold, Aldo, *Engineering and Conservation*, The River of God and Other Essays, pp 249-254, The University of Wisconsin Press, Madison, WI, 1991.
16. Leopold, Aldo, *The Land Ethic*, A Sand County Almanac With Essays on Conservation From Round River, Ballantine Books Edition, September 1970., pp 237-264.
17. Martersteck, Karl, *Personal Endorsement of a Change to ABET Criteria EC 2000*, Personal Communication, January 31, 2002. See also [25].
18. Meyers, Carolyn and Ernst, Edward W., *Restructuring Engineering Education: A Focus on Change, Division of Undergraduate Education*, Directorate for Education and Human Resources, National Science Foundation, Arlington, VA, April 1995.
19. Speth, James G. and Smart, S. Bruce, *The New Renaissance*, Business Week, June 18, 1990.
20. Splitt, Frank G., *The Challenge to Change: On Realizing the New Paradigm for Engineering Education*, Submitted to the *Journal of Engineering Education*, May 2002. See also [25].
21. Splitt, Frank G., *The Industrial Needs of the Engineer in the 21st Century: An Update*, ABET Annual Meeting, San Antonio, TX, Oct. 29, 1992; ASEE, New England Section, 71st Annual Fall Conference, Northeastern University, Boston, MA, Oct. 22, 1993.
22. Parrish, Edward A., *EC 2000: A Driver for Change*, Proceedings of the 1998 Engineering Foundation Conference, New York, NY, June 3-6, 1998.
23. World Business Council for Sustainable Development (WBCSD), *Eco-efficient Leadership for Improved Economic and Environmental Performance*, WBCSD, Conches-Geneva, Switzerland, 1996.
24. www.abet.org (ABET re: *Engineering Criteria 2000: Criterion 3 Programs Outcomes Assessment*)
25. www.ece.northwestern.edu/EXTERNAL/Splitt/ (Additional information re: [17] [20])
26. www.nap.edu (National Academy Press)
27. www.natcap.org (Natural Capitalism)
28. www.wbcsd.org (World Business Council on Sustainable Development)

NOTE: This paper was published in the October 2002 issue of the ASEE Journal of Engineering Education (JEE).

APPENDIX: SELECTED COMMENTARIES ON A PROPOSED CHANGE TO ABET EC 2000

"Thank you for your thoughtful concern for the structure of engineering education and your proposal, which is a model of simplicity with deep implications,"
Theodore A. Bickart, Accreditation Policy Council Chair, IEEE-Educational Activities Board, President Emeritus, Colorado School of Mines.

"I see this proposal as a reflection of the growing need to consider economic and environmental factors at the very beginning of engineering design and as a logical extension of ABET EC 2000. I also see the McCormick School using our *Engineering First* program to set the foundation for our student's learning that an understanding of their environmental responsibility will be an important outcome of their engineering education – an understanding that can be demonstrated by means of the student's capstone design project."
John Birge, Dean, Northwestern University's McCormick School of Engineering and Applied Science

"Although environment has been introduced into engineering curricula increasingly over the past several decades, its place is still not recognized formally as part of the contextual foundation for engineering education. The explicit inclusion of environment in the ABET criteria is long overdue and deserves an equal place next to ethical and professional responsibility."
John R. Ehrenfeld, Director Emeritus, MIT Technology, Business and Environment Program, Executive Director International Society for Industrial Ecology

"Environmental issues have become central to much engineering design and practice. Yet environmental questions remain peripheral, and sometimes are absent from, most engineering education. Environmental knowledge and skills should become much more central parts of engineering education, taking a natural place in engineering practice…."
Robert A. Frosch, Senior Research Fellow, Belfer Center for Science and International Affairs,
John F. Kennedy School of Government, Harvard University

"I have become acquainted with efforts to propose a seemingly minor but important and timely change to "ABET Engineering Criteria 2000" that would upgrade knowledge of environmental implications of engineering designs. I believe that such a move to foster and integrate environmental considerations BROADLY across engineering education is sorely needed. Essentially all engineering disciplines now play a role in the move toward "dematerialization" of net resource flows (lifecycle design) in providing goods and services."
John H. (Jack) Gibbons, (former) Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology

“Engineering is inherently concerned with the art of the practical, what can be done to better human existence at a reasonable cost. As the cost, in both lives and dollars, of past environmental neglect becomes ever more evident, both conscience and good business sense require that we pay more attention to this critical area. ABET can play an important role by highlighting the need in its accreditation criteria.”
Martin Hellman, Professor Emeritus of Electrical Engineering, Stanford University

"Your proposed change to add to Criterion 3 (f) of ABET Engineering Criteria 2000 the word "environmental" is a small, but important change. I know first hand that the inclusion of "professional" and "ethical" responsibilities in this criterion is being seriously adhered to by electrical engineering programs and ABET/IEEE evaluators. Hence, with the "environmental" in the criterion, I believe in a few years all undergraduate engineering programs will have imbedded environmental responsibilities into their curricula in some manner. Like many important changes in engineering education, they take longer to institutionalize than any of us wish….”
Kenneth Laker, Professor and Graduate Group Chair, University of Pennsylvania, Department of Electrical Engineering, Past President, IEEE

"I whole-heartedly endorse and support the proposal to add the requirement for knowledge of environmental responsibilities to the ABET criteria for ALL engineering graduates….let me emphasize that in my opinion engineers undoubtedly have the greatest potential (relative to virtually all other professions), not only for responsible environmental protection, but also for environmental improvement, as they carry out their various project tasks and activities. Engineers are in a unique position to positively impact the environment and clearly have a global responsibility to do so. This will never happen, or worse, the environment will be negatively impacted, if engineers are not educated properly regarding the environment. Admittedly, there is an ever-growing body of technical knowledge which must be imparted to engineering students. Hence, there will be a natural resistance among academics to further increase this burden with environmental material. Therefore, environmental concerns are not likely to find a place in most engineering curricula without a forcing function such as the ABET criteria….”
Karl Martersteck, Retired President and CEO, ArrayCom Inc., Former Vice President, AT&T Bell Laboratories.

"Protection of the environment is clearly one of the most important issues facing mankind today. It is an issue in which the engineering profession must have a key role. Engineering educators should be encouraged to bring environmental thinking to the attention of undergraduate engineering students. Your proposed addition of he word "environmental" to the ABET criteria should be a helpful step in this direction."
James M. McKelvey, Senior Professor of Chemical Engineering, Former Dean of Engineering (1964-91), Washington University, St. Louis.

“Engineers have a greater potential impact on our environmental inheritance than members of any other profession and we, therefore, have a greater obligation and responsibility to see to its care. It is a daunting responsibility, replete with ethical and professional pitfalls. Engineering universities and colleges have a duty to make their graduates aware of these responsibilities.”
Malcolm McPherson, Dean of Engineering, Virginia Polytechnic Institute and State University

“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.”
Manijeh Razeghi, Walter P. Murphy Professor, Director, Center for Quantum Devices, Department of Electrical and Computer Engineering, McCormick School of Engineering and Applied Science, Northwestern University

“The National Council for Science and the Environment (NCSE) strongly supports the proposal to add the word “environmental” to the ABET Engineering Criteria 2000, Criterion 3 so that the Criterion would read, “Engineering programs must demonstrate that their graduates have: (f) an understanding of professional, ethical, and environmental responsibilities”. We believe that this addition could be significant in helping to ensure that engineers are significant contributors to the challenges of environment and sustainability that are facing the inhabitants of planet Earth.”
Peter D. Saundry, Executive Director, National Council for Science and the Environment

"As you know, I've worked hard to REMOVE language from ABET requirements, but it seems to me the word you wish to add is, if properly interpreted, an obvious improvement. One would hope that in certain fields, such as chemical engineering where process design usually is oriented to avoid an end-of-pipe problem in the first place and civil engineering where environmental issues have long been important, the change would require almost no revision to current practice. In other areas, and I would include EE here, substantive changes might be in order. In any event, putting "environmental" on the same footing as "ethical" sounds good to me.”
William R. Schowalter, Dean Emeritus, Professor of Chemical Engineering Emeritus, University of Illinois at Urbana Champaign

PART II
The Challenge to Change: On Realizing the New Paradigm for Engineering Education

.

ABSTRACT

The new paradigm for engineering education goes beyond the need to keep students at the cutting edge of technology and calls for a better balance in the various areas of engineering school scholarship. There is considerable concern that perpetuation of the old paradigm by engineering schools will all but assure minor roles for engineers in the future as well as difficulty in adapting to the exigencies of the fast-paced global marketplace. However, the transition from the old to the new paradigm will not be easy since many of our research-intensive universities are faced with financial pressures while the wherewithal to make the change rests mostly with those who oppose the change in the first place. This situation, coupled with the fact that there is no "one-size-fits-all" transition paradigm, represents the challenge to change. Still, a number of engineering schools have made significant changes and have developed innovative approaches in their undergraduate programs. Taken together, the proven methodologies and knowledge gained should make it possible for most engineering schools to devise revitalization programs that fit the context of their institution, its student body, faculty, and objectives. This paper argues for an assessment study of the tools and methodologies developed by pace-setting engineering schools and the NSF Engineering Education Coalitions to lay the foundation for future reform initiatives.

I. INTRODUCTION AND PURPOSE

The introduction of Engineering Criteria 2000 by the Accreditation Board for Engineering and Technology (ABET) [1] and, beginning in the early 1990s, the funding of a number of programs related to systemic engineering education reform by the National Science Foundation (NSF) [2] are considered seminal events on the path to a new paradigm for engineering education. The 1998 Engineering Foundation Conference (EFC'98) – *Realizing the New Paradigm for Engineering Education* – co-chaired by Edward W. Ernst, University of South Carolina, and Irene C. Peden, University of Washington, provided further impetus to engineering education reform. At EFC'98, Ernst 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" [3].

One purpose of EFC'98 was to highlight a new program, *Action Agenda for Systemic Engineering Education Reform*, that stemmed from recommendations made at a July 1995 workshop convened by the NSF's Engineering Directorate [4], just after the publication of authoritative reports on engineering education reform by the American Society for Engineering Education (ASEE) [5] and the National Research Council (NRC) [6]. This new NSF program was to encourage proposals from the engineering education community [7]. However, following the conference, changes at the NSF Engineering Directorate led to changes in programmatic emphasis, and the Action Agenda Program was discontinued.

Achieving change via engineering education reform presents a formidable challenge. It is part of the overarching challenge of change, faced by universities and colleges throughout our nation, as described by Duderstadt [8] in his comprehensive analysis of the issues and the need for new paradigms. Others [9,10] have provided additional perspectives. This is a complex age of rapid change where different points of view and conflicting interests characterize the stakeholders who often resemble disconnected parties. Achieving change will not be easy given academe's bias toward preservation of the status quo where publications and research funding drive rewards and recognition. In the early 16th Century, Niccolo Machiavelli, a preeminent political observer and analyst, captured the essence of this type of situation when he wrote in The Prince: "There is nothing more difficult, to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things."

This paper is an updated version of the second part of a trilogy on engineering education reform [11]. In contrast to the first paper [12] that focused on environmentally smart engineering education, this paper addresses change related to the totality of attributes that define the new paradigm. The trilogy also includes a paper titled "Engineering Education Reform: A Path Forward." The specific purpose of the present paper is to provide some historical perspectives while renewing the call for a new paradigm in engineering education. The various stakeholders in the future of engineering education – administrators, faculty, students, parents, industry and government leaders, as well as many others – should better see the shape and dimensions of the dilemma in which they are immersed, be stimulated to debate, and motivated to continue acting along workable paths to implement widespread reform to ensure the vitality and currency of engineering education in the United States.

II. THE NEW PARADIGM FOR ENGINEERING EDUCATION

National Academy of Engineering (NAE) Chairman, George M. C. Fisher spoke at the 2001NAE Annual Meeting [13]. The implications of his remarks are profound. Along with the ASEE and NRC reports [5,6], Duderstadt's book [8] and the Boyer Commission Report [14], they provide valuable insights relevant to deliberations on engineering education reform. Fisher ended his talk by saying: "In conclusion I would remind us that with recognition comes responsibility. As NAE members you are the most accomplished and most respected members of the engineering profession. It is up to you to: 1) Widen your horizons. Be a Renaissance engineer – that is, an engineer for the 21st century, 2) Get involved in public policy. Don't be afraid to run for office. Stand for practical, cooperative solutions. Bring your expertise to the table and make others want to listen to you, 3) Most important, go out and change the world. Make it a better place. Improve the quality of life for all the people of the earth. Isn't that what engineering is really all about?"

What are the profound implications of Fisher's call for renaissance engineering? Renaissance engineers – men and women who get involved with public policy; run for office; stand for practical, cooperative solutions; work to change the world to make it a better place and improve the quality of life for all the people of the earth – first need to be educated in accordance with a new engineering-education paradigm.

There is concern that the perpetuation of the old paradigm by engineering schools will all but assure minor roles for engineers in the future – in accordance with the old adage, engineers are always on tap, rarely on top. Engineers are there to solve problems defined by others, along with imposed constraints on the solution, but not to set the agenda for problems to be solved. Samuel C. Florman's remarks [15] are to the point: "When C. Wright Mills wrote his widely-read book, The Power Elite, in 1956, he reported that engineers were typically reduced to the role of "a hired technician" with true power being vested in the "corporation chieftains and the political directorate." That was more tactful than Thorstein Veblen had been in 1917 when he wrote that the public viewed engineers as "a somewhat fantastic brotherhood of over-specialized cranks, not to be trusted out of sight except under the restraining hand of safe and sane businessmen." "Nor," he added, "are the technicians themselves in the habit of taking a greatly different view of their own case."

The new paradigm for engineering education is keyed to the fact that current and future demands will be for the solution of problems involving human values, attitudes, and behavior, as well as the interrelationships and dynamics of social, political, environmental, and economic systems on a global basis. It goes beyond the need to keep students at the cutting edge of technology and calls for a better balance in the various areas of engineering-school scholarship [5-7, 16-18]. This basic view was also reflected in industry perspectives [19-25], and by Florman [15], "If we want to develop Renaissance engineers, multi-talented men and women who will participate in the highest councils, we cannot educate them in vocational schools – even scientifically distinguished vocational schools – which is what many of our engineering colleges are becoming."

In his remarks at EFC'98, John Prados, University of Tennessee, said [7]: "Massively integrated populations place environmental protection, health, and safety at the front end of design; mandates for zero discharge, the need to consider total life-cycle costs for new products, and the impact of social and political concerns on engineering decisions have dramatically changed the economic basis of project evaluation." William Wulf, National Academy of Engineering, then put it another way [26], "Engineering is creating, designing what can be, but it is constrained by nature, by cost, by concerns of safety, reliability, environmental impact, manufacturability, maintainability, and many other such ilities." Prados [7] also outlined the salient attributes of the New Engineering Education Paradigm. These attributes have been modified to reflect the industrial perspective of the author and others [5, 6, 19-25] as follows:

- Encouragement of diverse student academic backgrounds and faculty dedicated to developing emerging professionals;

- Connection of solid mathematics and scientific knowledge foundation with engineering practices;
- Maintenance of regular, well-planned interaction with industry – including industry-based projects;
- Integration of subject matter, concepts, issues and principles – including relationships to earlier subject matter;
- Emphasis on inquiry-based learning and preparation for lifelong learning, with much less dependence on lectures;
- Stress on integrative, systems thinking, coping with change, communications skills (listening, speaking, reading, and writing), teamwork and group problem-solving skills (from identification through analysis and resolution);
- Focus on design issues involving life-cycle economics, environmental impact, sustainable development, ethics, timeliness, quality, health & safety, manufacturability, maintainability, social, legal, standards and ad hoc concerns.

It is to be noted that the application of design constraints/opportunities relating to life-cycle economics, environmental impact, and sustainable development, render what has come to be known as ecoefficient design [12]. No doubt, some of the details in the above list of attributes will change over time. However, programs that reflect these attributes will not only yield renaissance-engineer graduates with the tools to face an unpredictable future with confidence in their abilities, but also yield untold benefits to the world in which they will live.

In the end, it is likely that students that attend schools with programs that do not reflect these attributes will be disadvantaged. Just as a lack of diversity in a stock portfolio can spell disaster during downturns in the economy, so too will overspecialization in the engineering disciplines. This is yet another argument for educating well-rounded engineers who can address the variety of design challenges represented by the highly competitive, global marketplace and can also develop the capacity to adapt to the ups and downs of business cycles. Unfortunately, “deprived” students and schools form a mutually reinforcing couple. The problem with institutional indifference to the real needs of engineering graduates is that students have become desensitized to real-world needs that reach beyond the technical, and, as consequence, seem to be satisfied, regardless of conditions, so long as they graduate. Instead of being disappointed with their educational experience, the students are prone to rationalize – changing how they view their experience. The fact that students continue to attend such academic institutions is not indicative of anything in particular because they have adjusted to and accepted the condition as "normal," not realizing that they have been shortchanged.

III. THE CHALLENGE TO CHANGE

Alice Agogino, University of California-Berkeley, who served as the Director of the NSF *Synthesis Engineering Education Coalition*, has said: “We need different forums to move the 60 percent (beyond the 20 percent that are already working as change agents)” [27]. Forums and the like provide the opportunity and the wherewithal to develop traction to help propel us along the arduous path to commonplace academic acceptance of requisite change. However, the transition from the old to the new paradigm is likely to be quite difficult since the wherewithal to make the change rests mostly with those with entrenched interests who resist change in the first place. This resistance to change, coupled with the fact that there is no “one-size-fits-all” transition paradigm, represents the challenge to change.

Ultimately, deans and their faculty will be critical to successful transitioning; however, as Wulf [26] has stated, “For the most part our faculty are superb “engineering scientists,” but they are not necessarily folks who know a lot about the practice of engineering…. the current faculty are the folks with the largest say in engineering curriculum. Given this, it should not be a big surprise that industry leaders have been increasingly vocal about their discontent with engineering graduates.” Furthermore, it is difficult for some deans and faculty to address the compelling need to educate their students in accordance with the new paradigm when their “benefits,” new research funding and derivative prestige, faculty promotion, tenure, honors and corresponding high external rankings, by such as U.S. News & World Report, depend on an infrastructure in which “grantsmanship” is valued over the ability to educate undergraduates. These benefits also provide positive feedback in that “success” attracts more and better researchers, more benefits and a continued lock on their strategy. “They might claim otherwise, but research universities consider “success” and “research productivity” to be virtually synonymous terms [14].” This is yet another example of “you get what you reward!” A balanced strategy would recognize that a continued focus on traditional benefits can be counterproductive and so would demonstrate a commitment to undergraduate teaching as well as research – reflected in promotion and tenure decisions. However, the rules of the "zero-sum" game seem to dominate the worldview of those opposed to change, governing the dynamic tension that characterizes most aspects of the research vs. engineering-education struggle – ranging from NSF program budgets to the "pecking order" at our engineering schools, and, for that matter, at award granting organizations.

Apparently, what some of our deans of engineering and faculty may not realize is that they are a part of an academic business enterprise, and, as such, when and where appropriate, they ought to think and act as competitive businesspersons. Information Technology (IT) has changed the "rules-of-the-game," for the engineering-education business [8, 17, 18, 28, 29]. Competitors are not limited to other universities and colleges. Alternate providers, enabled by IT and the awesome power of networking, can provide anytime, anywhere educational programs (to almost anybody) at relatively lower cost than most, if not all, universities and colleges. According to the Wall Street Journal [30] some $6 billion in venture capital has flowed into the education sector since 1990 – almost half of it since 1999 when John Chambers, Cisco Systems, claimed that education would be "the next killer application on the internet," and what analysts estimate to be a $250 billion market.

Engineering schools need a decisive competitive advantage over all of their competitors if they are to continue as leading providers of engineering education. A decisive competitive advantage should differentiate the schools from alternative service providers. A competitive advantage in research is not considered sufficient, although it can complement an engineering school's selected strategy. The education process itself can provide the basis for competitive advantage with graduates providing the real payoff in the marketplace by virtue of a superior selection, education and formation process that takes place in a learning environment engineered for excellence.

This excellence in engineering education would be manifested in instruction, mentoring, role modeling, and guidance that reflect the attributes of the new paradigm, wherein emphasis is placed on communications and leadership skill development, teamwork and close interaction, systems thinking, ecoefficient design, and lifelong learning – learning what to learn and how to learn it. Noam [29], put it another way: "The strength of the future physical university lies less in pure information and more in college as a community; less in wholesale lecture, and more in individual tutorial; less in Cyber-U and more in Goodbye-Mr.-Chips College." It will be of interest to watch the progress at the new Franklin W. Olin College of Engineering as they start "from scratch" to implement the results of Invention 2000, Olin's two-year effort to fundamentally rethink the way engineers are taught and the way colleges function [31].

Engineering deans and faculty are faced with the academic-institution variant of the innovator's dilemma [12], manifested by the general challenge of innovation in successful organizations. It seems ironic that those deans and faculty who ardently defend the status quo could be unwittingly undermining the long-term viability of their engineering school in the engineering education marketplace. As illustrated in the following section, the NSF Coalitions and EFC'98 have served as counter forces to this influence.

IV. PARADIGM SHIFTERS AND SUPPORTERS

A. Paradigm Shifting Engineering Schools

Many engineering schools have made significant changes in their undergraduate programs – on their own, or with the help of NSF and other grants. These changes encompass all or some of the attributes of the new paradigm. Additionally, some schools have developed cross-disciplinary programs involving engineering with: management, manufacturing, medicine, law, political science, biology, and other life sciences.

At ECF'98, numerous participants stepped up to the challenge to change. They did this by sharing their experiences with change at their institutions and focusing on the following three key questions in several workshop sessions: 1) How can we use the challenges of the engineering workplace, ABET Engineering Criteria 2000 and experiences of others to create change at my institution? 2) How can we use information technology and the experiences of others to create change at my institution? 3) What can we do to institute engineering education reform and what is my part in doing this?

Presentations (documented in the EFC'98 Proceedings) were made by the following "paradigm-shifting" engineering schools: Massachusetts Institute of Technology, Harvey Mudd College, Colorado School of Mines, Worcester Polytechnic Institute, Drexel University, Texas A&M University, Rose-Hulman Institute of Technology, Columbia University, and the University of Colorado at Boulder. Each of the presentations illustrated that, given the right circumstances, change is indeed possible. The presentations also reflected on "what works" and revealed innovative approaches to achieving the new paradigm in engineering education. In fact, Eli Fromm, Drexel University was awarded the Inaugural NAE Bernard M. Gordon Prize for the Enhanced Educational Experience for Engineers program that led to the NSF *Gateway Engineering Education Coalition*. EFC'98 Workshop deliberations and conclusions were summarized by Ernst [32] who also assembled and edited a review of references on engineering education for the period 1981-1997 [33].

Specific actions and new approaches have also been taken at: Georgia Institute of Technology, Mississippi State, Northwestern University, Stanford University, University of Illinois at Urbana-Champaign, University of Notre Dame, University of South Carolina, University of Tennessee at Knoxville, and Virginia Tech. Although by no means exhaustive, the programs at these research universities represent approaches that can be used to accelerate change. A brief description of these programs has been compiled by the author [34]. Still more examples of change are "side-barred" in the Boyer Commission Report [14].

B. NSF Engineering Education Coalitions (EECs)

The goal of the NSF EECs has been to stimulate the creation of bold, innovative, and comprehensive models for systemic reform of undergraduate engineering education [2]. A further goal has been to increase the retention of students, especially women and those minorities underrepresented in engineering. To accomplish this reform, eight NSF EECs worked to develop education tools, curricula, and delivery systems aimed at increasing the successful participation of under-represented groups in engineering education and to improve linkages to K-14 educational institutions. The NSF EECs were instrumental in realizing nation-wide efforts in improved outcomes assessment of learning and the development of ABET EC 2000. Of the eight original NSF EECs, six have completed their work while two are in the process of completion.

Through cross-coalition collaboration, the NSF EECs developed intellectual exchange and resource links among undergraduate engineering programs. Annual *Share the Future* Conferences were initiated in 2000. These conferences offer a variety of workshops centered on topics relevant to the NSF EEC's goals – providing the extended engineering education community an opportunity to share in the research findings and experiences of the EECs. For example, the titles of some of the workshops offered at the March 2002 *Share the Future III* Conference, were as follows: Course Evaluation for Measuring Learning Objectives, Reality-based E-learning Activities, Curriculum Integration: How and Why, Comprehensive Assessment of Design Projects, Instructional Technologies in the Classroom, Course Objectives and Classroom Assessment, Effective Teaching with Technology, Building a Freshman Engineering Program, Designing Innovative Classrooms, Facilitating Change in First-year Engineering Instruction, Active Classroom Learning with Media, A Unified Approach to Engineering Science, and Writing Stronger Engineering Education Proposals. Information on the March 2003 *Share the Future IV* Conference, sponsored by the *Foundation, Gateway, Greenfield, and SUCCEED Coalitions*, can be found at the conference Web site [49].

C. International Engineering Consortium (IEC) Initiatives

A review of the IEC's educational and other programs [36], led to discussions on the potential of Web-based environmental education in connection with an educational and environmental initiative [12]. Discussion centered on development of asynchronous-learning resources to provide materials/courseware, similar to the IEC's *ProForums* and *iForums*, that could be used by all engineering schools to provide environmental education for engineering students in every discipline if they elect to do so. In addition, the IEC and the Electrical and Computer Engineering Department Heads Association (ECEDHA) [37] are working together to extend the *ProForums* into the classroom for all engineering schools. This on-line resource capability could also be used to enrich the student's learning experience in ethics, health & safety, legal and other "real-world" aspects of engineering.

D. NAE Educational Initiatives

The stated mission of the NAE's Committee on Engineering Education (CEE) is to ensure the vitality and currency of engineering education in the United States. To this end, the CEE has launched several projects, the following three of which relate to realization of the new paradigm in engineering education [38].

- Engineer of 2020:Visions of Engineering Work and Education in the New Century
- Information Technology in Engineering Education
- A Center for Scholarship in Engineering Education at the NAE

V. LOOKING FORWARD

The root question, What is an engineering education for? – and its corollary, What is engineering really all about? – should be on the table for an evolutionary debate re: the future of engineering education. What engineering students need to learn and how/where can they best learn it, as well as what engineering schools should teach and how/where can they best teach it are among the "questions" to be considered. The "what" lies at the crux of the matter. It is my view that what is taught and learned at the undergraduate level should include much more than the technically circumscribed material that is sometimes presented in studies of the future of engineering education. Certainly, there are other views and conflicting interests. That is why all stakeholders need to come together to better understand opposing interests and work to evolve the best path forward.

Answers to the "what' questions require an infusion of wisdom, understanding, breakthrough thinking, and perseverance. As evidenced by the set of previous references, considerable thinking and effort has already been put forth. To this infusion can be added the work of still others [39-45]. Perhaps more important will be the voice of industry – one of the prime "customers" of academia. Karl Martersteck, a former vice president at AT&T Bell Laboratories and former president and CEO of ArrayComm, put it this way: "without forceful input from industry, academia will not be very motivated to institute changes in their engineering curricula. Industry must establish the "requirements" for the quality and education of the engineers they hire. Unless, and until, major industrial leaders whose views are generally respected speak out and say that they will not hire engineers unless the engineers have the broader "new paradigm" education, academics will continue to pursue their present course [46]." Engineering school advisory boards can serve as voices of industry; however, many existing boards will likely require a restructuring to accomplish this mission.

Eventually, the extant barriers to real progress in the quest to achieve ubiquitous realization of the new paradigm in engineering education will break down. Building on the wealth of knowledge and experience of others, change agents will continue working to catalyze widespread reform aimed at fundamental change – systemic change that lies well beyond rhetoric and cosmetic experiments. Abundant guidance for this work-in-progress can be found in the Action Plan set forth in the ASEE *Green Report* [5], the NRC Report's Call to Action [6], the Action Agendas suggested by Peden, Ernst, Prados and Duderstadt [4,8], the Boyer Commission's Ten Ways to Change Undergraduate Education [14], and the Wulf-Fisher Agenda for Change [45]. The NSF, ASEE, NAE, ABET, NCSE, as well as industry leaders and forward-looking university faculty and administrations can contribute to the effort – each in their own way. As discussed in *Engineering Education Reform: A Path Forward* [11, pp.15-21], the NAE is particularly well positioned to provide leadership by example. Engineering professional societies, organizations, forums, department heads associations, and the IEC can contribute as facilitators and agents of change.

Although, there has been good progress over the three years since the publication of the Boyer Report [47], resistance to change continues, notwithstanding increasing competition from alternate service providers as well as apparent "student-pipeline" and job-security problems that have now been brought to national attention [48-50]. The time is right to initiate a follow-up study, similar to that of the Committee on Evaluation of Engineering Education, coincidentally just after the 50th-anniversary year of the formation of the original Committee, appointed by ASEE President S. C. Hollister in May, 1952 and chaired by Linton E. Grinter. The idea of another study, similar to the one that led to the Grinter Report in 1955, is not new. A pathfinder study committee to guide the development and reformation of engineering education was suggested in 1994 by William Grogan and echoed by Irene Peden and John Whinnery in a Journal of Engineering Education Roundtable [51]. Most recently, Jerrier Haddad suggested a formal study addressed to the related issue of the significant decline in enrollments for engineering programs [52].

This study would follow through on the assessment effort outlined in the preface of the 1994 *Green Report* [4]: "Over the next few years, the ASEE Engineering Deans Council will lead the effort to assess what engineering colleges are doing to affect change, refine the action items of the report, and set milestones for assessing future progress toward their implementation." Much has happened in the eight years since the release of the *Green Report*. Of specific interest, would be an assessment of the breath and depth of adoption/penetration of the tools and methodologies developed by pace-setting engineering schools and the NSF EECs. Also of interest would be the establishment of an agenda for catalyzing change as well as assessing future progress toward systemic and sustainable engineering education reform. The study would be best conducted by an "arms-length" group working with the benefit of the wealth of knowledge and experience gained over recent years. The charge to the pathfinder group would be: to recommend the course, or courses, that engineering schools should take in order to keep pace with the rapid developments in science, technology, and global affairs and to educate students who will be competent to serve the needs of and provide leadership for engineering and other professions, industry, and government.

VI. CONCLUDING REMARKS

The introduction of ABET EC 2000 and the establishment of the NSF EECs are considered seminal events on the path to a new paradigm for engineering education. As was seen at EFC'98, a number of engineering schools have made significant changes in their undergraduate programs – on their own, or with the help of NSF and other grants.

These changes encompass all, or some, of the attributes of the new paradigm. In addition to these "success stories" a number of other universities and colleges are involved with innovative approaches to change in undergraduate education. Taken together, the proven methodologies and knowledge gained as to what does, and does not work, should make it possible for most engineering schools to tap into and devise revitalization programs that fit the context of their institution, its student body, faculty, and objectives.

Finally, we cannot know exactly what the future will bring; however, we can predict with certainty that engineering schools and engineers will be called upon to satisfy a multiplicity of needs in the years to come. These needs may relate to knowledge and expertise, for example, in more secure and efficient physical facilities and information networks, advanced asynchronous learning systems, earth systems, and ecoefficient design of complex systems. Engineers will not only ponder problems involving new technologies, but world cultures, religions, ethics, and economics as well. They will also be concerned with other unforeseen questions of local, national, or global significance. Commitment to the realization of the new paradigm in engineering education will not only yield renaissance-engineer graduates with the tools to face an unpredictable future with confidence in their abilities, but also yield untold benefits to the world in which they will live. Despite the challenging environment and the difficulties involved, resiliency can be seen in the effort to realize the new paradigm in engineering education – resiliency that is essential in responding to what ought to be considered among the grander challenges of the 21st Century.

ACKNOWLEDGEMENTS

Many thanks are due all those who contributed to the development of this paper. Ted Bickart, Ed Ernst, and John Prados provided critical reviews of the near final drafts while Tim Trick, Karl Martersteck, and Roger Webb did the same for early drafts. Alice Agogino, Wayne Bennett, John Birge, Steve Carr, Dick Carsello, Lyle Feisel, Eli Fromm, Jerry Haddad, Martin Hellman, Bob Janowiak, Russel Jones, Bruce Kramer, Bill Lindsey, Malcolm McPherson, Irene Peden, Manijeh Razeghi, Jim Roberts, Kay Vaughan, and Jim Vaughan provided valuable insights and encouragement with their commentaries. I am grateful to Jack Lohmann and the ASEE JEE reviewers for many helpful suggestions. I also want to thank Mary Leming and the Boyer Commission on Educating Undergraduates in the Research University for helping me reintroduce Ernest L. Boyer's prescient views on undergraduate-education reform to the engineering community. Finally, I want to express my deep gratitude to Professor Ernst who played an important role in my work, as both a mentor and a facilitator, within the academic and engineering accreditation communities.

REFERENCES

1. *Criteria for Accrediting Engineering Programs*, Baltimore, Maryland: Accreditation Board for Engineering and Technology (ABET), Dec. 26, 2000.
2. <www.eng.nsf.gov/eec/>, accessed January 5, 2003.
3. Ernst, Edward W., *Proceedings of the 1998 Engineering Foundation Conference*, *Preface,* New York, New York: Engineering Foundation.
4. Peden, Irene C., Ernst, Edward W., and Prados, John W., *Systemic Engineering Education Reform: An Action Agenda*, Washington, DC: National Science Foundation, July 1995.
5. American Society for Engineering Education Deans Council and Corporate Roundtable, *The Green Report: Engineering Education for a Changing World,* Washington, DC: American Society for Engineering Education, October 1994.
6. National Research Council's Board on Engineering Education (BEEd), *Engineering Education: Designing an Adaptive System*, National Research Council Report, Washington, DC: National Academy Press, 1995.
7. Prados, John W., "Action Agenda for Systemic Engineering Education Reform: Next Steps," *Proceedings of the 1998 Engineering Foundation Conference*, New York, New York: Engineering Foundation, pp. 1-13.
8. Duderstadt, James J. J., *A University for the 21st Century*, 1st ed., Ann Arbor, Michigan: University of Michigan Press, September 1999.
9. Altbach, Philip G. et al, *American Higher Education in the Twenty-First Century: Social, Political, and Economic Challenges*, Baltimore, Maryland: Johns Hopkins University Press, November 1998.
10. "Survey of Universities, Inside the Knowledge Factory," *The Economist*, October 4, 1997, pp. 3-22.
11. Splitt, Frank G., *Engineering Education Reform: A Trilogy*, Chicago, Illinois: International Engineering Consortium, October 2002.

12. Splitt, Frank G., “Environmentally Smart Engineering Education: A Brief on a Paradigm in Progress,” *Journal of Engineering Education*, Vol. 91, No. 4, 2002*,* pp. 447-450.
13. Fisher, George M. C., “Renaissance Engineers of the Future,” *The Bridge*, Vol. 31, No. 4, 2001, pp. 32-34.
14. Kenny, Shirley Strum (Commission Chair), *Reinventing Undergraduate Education: A Blueprint for America’s Research Universities*, The Boyer Commission Report on Educating Undergraduates in the Research University, Stony Brook, New York: The Carnegie Foundation for the Advancement of Teaching, 1998.
15. Florman, Samuel C., “Engineering and the Concept of the Elite,” *The Bridge*, Vol. 21, No. 3, 1991, pp. 11-17.,
16. Boyer, Ernest L., *Scholarship Reconsidered: Priorities of the Professoriate*, Stony Brook, New York: Carnegie Foundation for the Advancement of Teaching, December 1990.
17. Denning, Peter J., “Educating a New Engineer,” *Communications of the ACM*, Vol. 35, No. 12, 1992, pp. 83-97.
18. Pister, Karl S., “A Context for Change in Engineering Education,” *Journal of Engineering Education*, Vol. 82, No. 2, 1993, pp. 66-69.
19. Splitt, Frank G., “Too Few Generalists: A Problem for Engineering Education,” Chairman’s Address at the 1986 National Communications Forum, <*www.ece.northwestern.edu/EXTERNAL/Splitt/*>*,* accessed January 5, 2003.
20. Splitt, Frank G., “The Industrial Needs of the Engineer in the 21^{st} Century,” *1991Annual Conference of the ASEE*, New Orleans, Louisiana, <*www.ece.northwestern.edu/EXTERNAL/Splitt/*>, accessed January 5, 2003.
21. Splitt, Frank G., “Creating Our Common Future – Reflections on the 4 Es: Environment, Education, Energy, and Economics,” <*www.ece.northwestern.edu/EXTERNAL/Splitt/*>*,* accessed January 5, 2003, *The Bent of Tau Beta Pi*, Vol.83, No. 4, 1992, pp. 29-32.
22. Splitt, Frank G., “The Industrial Needs of the Engineer in the 21^{st} Century: An Update,” *71^{st} Annual Fall Conference of the New England Section of the American Society for Engineering Education*, Boston, Massachusetts, October 22, 1993, <*www.ece.northwestern.edu/EXTERNAL/Splitt/*>*,* accessed January 5, 2003.
23. Splitt, Frank G., et al, “Real World 101: What Some Engineers in Industry Want Your Students, and You, to Know,” *ASEE Prism*, Vol. 2, No. 2, October 1992, (Cover story composed by *ASEE Prism* Editor).
24. Geppert, Linda, “Educating the Renaissance Engineer,” *IEEE Spectrum*, September 1995, pp. 39-43.
25. Augustine, Norman R., “Socioengineering,” *The Bridge*, Vol. 24, No.3, 1994, pp 3-14.
26. Wulf, William A., “The Urgency of Engineering Education Reform,” *The Bridge*, Vol. 28, No. 1, 1998, pp. 4-8.
27. Agogino, Alice M., *Proceedings of the 1998 Engineering Foundation Conference*, *Edited Transcripts of the Workshop Presentations,* New York, New York: Engineering Foundation, pp. 124-128.
28. Wulf, William, A., “Warning: Information Technology Will Transform the University,” *Issues in Science and Technology*, Summer 1995.
29. Noam, Eli M., “Electronics and the Dim View of the University,” *Science*, Vol. 270, October 13, 1995.
30. Grimes, Ann, “On the Battlefield: A Matter of Degree,” *The Wall Street Journal*, page R29, July 17, 2000.
31. <*www.olin.edu*>*,* accessed January 5, 2003.
32. Ernst, Edward W., “Realizing the New Paradigm in Engineering Education: Summary of Workshop Sessions”, *Proceedings of the 1998 Engineering Foundation Conference*, New York, New York: Engineering Foundation, pp.121-123.
33. Ernst, Edward W., “Review of Reports, Studies, and Conferences on Engineering Education: 1981-1997,” *Proceedings of the 1998 Engineering Foundation Conference*, New York, New York: Engineering Foundation, pp. 129-141.
34. <*www.ece.northwestern.edu/EXTERNAL/Splitt/*>, (A Brief on Some Paradigm Shifting Schools) accessed January 28 , 2003.
35. <*http//foundationcoalition.org/events/conferences/share_the_future_iv.html*>, accessed January 7, 2003.
36. <*www.iec.org*>, accessed January 5, 2003.
37. <*www.ecedha.org*>, accessed January 5, 2003.
38. <*www.nae.edu*>, accessed January 5, 2003.
39. Janowiak, Robert M., and Sheth, Jagdish, *2021 AD: Visions of the Future, The ComForum Summary and Research Report*, Chicago, Illinois, National Engineering Consortium, 1991.
40. Borgdona, Joseph, “The Professional Engineer in 2010,” *Proceedings of the 1998 Engineering Foundation Conference*, New York, New York: Engineering Foundation, pp.14-27.
41. Vest, Charles M., “U.S. Engineering Education in Transition,” *The Bridge*, Vol. 25, No. 4, 1995, pp 4-9.
42. Bordogna, Joseph, Fromm, Eli, and Ernst, Edward W., “Engineering Education Innovation Through Integration,” *Journal of Engineering Education*, Vol. 82, No. 1, 1993, pp. 3-6.

43. Myers, Philip S., “Teaching versus Research – Incompatibility or Overemphasis?,” *Journal of Engineering Education*, Vol. 82, No. 1, 1993, pp. 22-26.
44. Ernst, Edward W., “Engineering Plus: Challenges and Choices,” *IEEE Transactions on Education*, Vol. 31, No. 2, 1988, pp. 137-139.
45. Wulf, William A. and Fisher, George M. C., “A Makeover for Engineering Education”, *Issues in Science and Technology*, Spring 2002, <http://www.nap.edu/issues/18.3/p_wulf.html>, accessed January 6, 2003.
46. Martersteck, Karl, *Personal Communication*, May 1, 2002. See also Personal Endorsements [46].
47. Kenny, Shirley Strum (Commission Chair), *Reinventing Undergraduate Education: Three Years After the Boyer Report*,” The Boyer Commission Report on Educating Undergraduates in the Research University, Stony Brook, New York: The Carnegie Foundation for the Advancement of Teaching, 2002.
48. Begley, Sharon, “As We Lose Engineers, Who Will Take Us Into the Future?,” *The Wall Street Journal*, page B1, June 7, 2002.
49. Begley, Sharon, “Angry Engineers Blame Shortage on Low Pay, Layoffs and Age Bias,” *The Wall Street Journal*, page B1, July 5, 2002.
50. Jones, Russel C. and Oberst, Bethany S., “Are Current Graduates in the US Being Treated as Commodities by Employers?,” *Proceedings of the 2002 ASEE Conference and Exposition*, Session 1460, June 2002.
51. Harris, James G. (Moderator and Organizer), DeLoatch, Eugene M., Grogan, William R., Peden, Irene C., and Whinnery, John R. (Participants), *Journal of Engineering Education Roundtable: Reflections on the Grinter Report, Journal of Engineering Education*, Vol. 83, No. 1, 1994, pp. 69-94.
52. Haddad, Jerrier A., Personal Communication, June 29, 2002.

NOTE; This paper has been accepted for publication in the April 2003 issue of the ASEE Journal of Engineering Education (JEE).

PART III
Engineering Education Reform: A Path Forward

ABSTRACT

A compelling case for engineering education reform has been made over the past 16 years. Although there has been progress, resistance to change continues unabated, notwithstanding the numerous calls for action, increasing competition from alternate service providers, as well as "student-pipeline" and job-security problems. The engineering education reform movement has been clouded by mixed, and sometimes conflicting, messages. This paper identifies this and other core problems impeding progress. The NAE is seen as taking a more active part in engineering education reform – taking action to help identify and resolve some of the vexing problems faced by engineering education reform, and, most important, leading by example.

I. BACKGROUND AND INTRODUCTION

A myriad of articles, papers, books, workshop and conference proceedings, and more have made a compelling case for engineering education reform. Among these are the 1994 ASEE Green Report [1], the 1995 NRC BEEd Report [2], and recent calls for change by the NAE leadership, President, William F. Wulf and Chairman, George M. C. Fisher [3, 4]. Working together, then NAE Chairman Norman Augustine and MIT President Charles Vest, led the effort behind the formulation of the authoritative ASEE and NRC reports. In fact, Vest chaired the NRC's Report Review Committee while Augustine wrote the Foreword for the NRC BEEd Report, wherein, he agreed with the report's conclusion: "…*that, in many areas, major change in the engineering education system is indeed necessary if it is to meet the needs of the nation and the world in the coming century*." [2, p vii].

Although there has been progress, resistance to change continues unabated, notwithstanding the numerous calls for action, increasing competition from alternate service providers, as well as "student-pipeline" and job-security problems that have been brought to national attention. There appears to be no clear path forward and an apparent absence of focused, action-oriented leadership. Additionally, recent times have seen the engineering education reform movement clouded by mixed, and sometimes conflicting, messages, for example:

- An assessment effort was outlined in the preface of the 1994 ASEE Green Report as follows: "*Over the next few years, the ASEE Engineering Deans Council will lead the effort to assess what engineering colleges are doing to affect change, refine the action items of the report, and set milestones for assessing future progress toward their implementation*" [1, p 1]. The follow-up assessment effort was never implemented.

- The epilogue of the NRC BEEd Report opens with: "*The BEEd is well aware that major changes in large, decentralized systems, such as the engineering education system, are seldom realized as a direct consequence of a single stimulus such as this report. Rather, such changes usually reflect a gradual shifting of opinions, attitudes, and practices arising from a recognition and clearer understanding of new external conditions and concomitant new internal needs and emphases*." [2, p 55]. True enough, but, to some, in contrast to the tone set in the Foreword and main body of the report, the words could be interpreted as a disclaimer or "escape clause" – providing a pass on implementing change, saying, in effect, that there need be no sense of urgency about engineering education reform. The statement could also be interpreted as a hedge – cautioning against unrealistic expectations, such as the timely adoption of the needed changes in engineering education spelled out in the main body of the report.

- One purpose of the 1998 Engineering Foundation Conference – Realizing the New Paradigm for Engineering *Education,* was to highlight a new program, *Action Agenda for Systemic Engineering Education Reform* that stemmed from recommendations made at a July 1995 workshop convened by the Engineering Directorate of the National Science Foundation [5]. This new program was to be administered through the NSF Engineering Directorate, and was to encourage proposals to this program from the engineering education community. Following the conference, changes at the NSF Engineering Directorate led to changes in programmatic emphasis, and the Action Agenda Program was discontinued after the first two rounds of awards.

- "*Thus if engineering education does not change significantly, and soon, things will only get worse over time. The problem has now been studied to death, and the solution is clear. So let's get on with it. It's urgent that we do so*," said Wulf and Fisher in the latest published word on the emphasis to be placed on engineering education reform [3].

- The philosopher Alfred North Whitehead remarked, "*The task of the university is the creation of the future, so far as rational thought, and civilized modes of appreciation, can affect the issue*." In a recent article, Stanley Katz used this remark to initiate his questioning the role of the modern university. "*But for many of today's academics, rationality is in question, civilization is anathema, and universities have not created, for themselves or for their societies, the future Whitehead envisaged. What, then, are we about? If, as Stanley O. Ikenberry, former president of the American Council of Education, has claimed, American universities are "at the top of their game," then just what game are they playing, and what's the prize*? [6]"

Although it was most encouraging to see the Wulf-Fisher statement, and Wulf's strong reiteration of this message at the 2002 ASEE Annual Conference this past June [4], the previous events and statements sent disquieting messages of equivocation to those who have worked, and are still working, in the engineering education reform movement, and who might have expected much more rapid progress after the publication and widespread promulgation of the ASEE and NRC reports than was seen up through 1995. It is troubling not to see the development of a shared sense of purpose within the engineering education community since the publication of the 1986 NRC Report on Engineering Undergraduate Education [7]. It is also troubling to see that this sense of purpose must be developed within university communities that are in need of transformation themselves [8] – university communities that are very likely not "at the top of their game" as seen by Katz.

Change continues to proceed at geologic speed despite the ardent efforts of Augustine, Vest and many others during the mid-1990s. Why might this be so and what might be done to accelerate the pace of change? These are obvious questions, the answers to which are complex and institution dependent, not amenable to a one-size-fits-all resolution. Nonetheless, after a brief discussion of interrelated problems, a path forward is proposed in the following. The NAE is seen as playing a major role – taking a more active part in engineering education reform than heretofore – unequivocally demonstrating that: "*it is strongly committed to moving engineering education's center of gravity to a position relevant to the needs of 21st-century society*" [3]. This means moving beyond the present set of Academy programs in this area [3, 4] to a new level – taking action to help identify and resolve some of the vexing problems impeding progress in engineering education reform, and, most important, leading by example.

II. ENGINEERING EDUCATION REFORM: SOME CORE PROBLEMS

According to the Boyer Commission: "…*universities too often continue to behave with complacency, indifference, or forgetfulness toward that constituency whose support is vital to the academic enterprise*" [9, p 37]. A survey conducted three years after publication of the Boyer Commission Report indicated that research universities have made considerable headway in recent years [10]. However, the survey "*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*."

It is believed that there is much more behind the reticence of some of our engineering schools to adopt change than complacency, indifference, forgetfulness, and even the routine resistance to change that characterizes organizations and institutions that consider themselves "successful" in doing what they are currently doing. In fact, there are powerful interrelated counter-reform forces at work, or, put another way, interdependent forces that work to maintain the status quo. Engineering education reform is at least partially dependent on the resolution of some of the interrelated problems; of these, the following are considered core problems:

A. Academic Resistance to Change

In the academic variant of the "innovator's dilemma" [11, p 448], many of our research-intensive universities, faced with enormous financial pressure, struggle to maintain and grow the (largely) government-fueled, resource-intensive infrastructure created to pursue their research missions [6, 8]. Apparently, it is their view that they cannot afford to invest human and physical resources in undergraduate engineering education reform where they perceive little, if any, near-term gain in the way of financial rewards or other payoffs that will help support their primary research mission.

Additionally, a generation or more of faculty members have been hired and promoted at many of our research-intensive institutions primarily because of their strengths in research and "grantsmanship." Relative to undergraduate teaching, many of these faculty members consider research to be inherently more personally fulfilling, more valuable to the profession and society, and more rewarding in terms of awards, prestige, and honors – including potential for election to the NAE. Additionally, the continued presence of faculty unions may hamper efforts to change faculty incentive systems [2, p. 32].

The deans, faculty, and administrations who oppose change could be unwittingly undermining the long-term viability of their engineering schools in the engineering education marketplace. It is not surprising, that opposition to change can come from some of the contributors to the NRC study – not surprising, since most people ultimately act in what they see as their near-term, vested self-interest.

B. Academic Resistance to ABET Oversight and Accountability

The NRC BEEd Report contains the following recommended action: "*The Engineering Dean's Council or other appropriate group should continue working cooperatively with the Accreditation Board for Engineering and Technology in its reassessment of accreditation criteria in accordance with the types of changes suggested in this report and implemented in response to current and future needs in engineering education*" [2, p 53]. The types of changes suggested in the NRC BEEd Report, are not likely to take place in most engineering school curricula without a forcing function such as the ABET criteria. Unfortunately, the very mention of ABET to engineering administrators and faculty often brings out powerful negative emotions and the perception of an imposed solution – an automatic trigger for opposition. ABET also brings to the table problems related to perceptions of remnant "bean counting" and an almost insatiable appetite for data. Based on their past experience and deep-seated, bad, memories of ABET's old bean-counting ways, it should come as no surprise that a good number of the schools tend to look past the merits and opportunities related to change. They will likely view any potential change in ABET EC 2000 as a precedent-setting threat to their academic autonomy and a first step on the "slippery slope" to the return of ABET bean-counting "with different colored beans."

To find an example that illustrates contrary behavior and the strong opposition that can be mounted against the types of changes suggested in the NRC BEEd Report, one need look no further then a January 2002 request for endorsements of a proposed one-word change to ABET EC 2000 – adding the word environmental to Criterion 3f [10, p 448]. Academic opposition to the proposed change seemed based on ABET involvement in the process, rather than on the substance of the proposal.

Further to the point, consider an "ideal-world" process wherein engineering schools, after a self assessment of their missions, decided to incorporate changes recommended in the NRC BEEd Report that are appropriate to their stated missions. In other words, each school exercised its freedom to devise a revitalization program that fits the context of their institution, their student body, faculty, and objectives. To assure that the schools are doing what they said they would do, suppose that the expected outcomes of their programs are gauged by the ABET EC 2000 process relative to the school's goals. Experience teaches that, under present, real-world circumstances, it is not likely that this ideal process will ever be implemented. It is only "natural" that the faculty will resist additional workloads for which there is little, if anything, in the way of rewards or recognition. Aside from "doing the right thing" for their undergraduate engineering students, they have little incentive to do otherwise.

The apparent opposition-to-reform strategy is to treat ABET in an adversarial manner, providing as little support as possible – reflecting the short-term, operational advantage attendant to a "weak" oversight function and the low value placed on activities that are not related to the school's research mission. The adversarial relationship between some of our leading engineering schools and ABET is considered one of the more vexing problems impeding progress in engineering education reform.

C. Academic Resistance to Electing Qualified Engineering Educators to the NAE

When considering resistance to change at various levels of the academic enterprise, the real issue is not whether research is favored over teaching, but how best to tie research to teaching in the most productive way, or, to redefine research to include teaching [11, p 23]. However, the recent history of engineering education reform suggests that the rules of the "zero-sum" game dominate the mentality of those opposed to change and governs the dynamic tension that characterizes all aspects of the engineering-research vs. engineering-education-practitioner struggle – from NSF program budgets to the "pecking order" at our engineering schools, and, for that matter at the NAE.

The predominance of engineer-researcher NAE members, appears to provide strong positive feedback, via engineering-school rankings by US News and World Report (USNWR), promotion and tenure decisions, and various other "reward and recognition" mechanisms, that works to maintain the status quo in engineering education at our research-intensive engineering schools as well as at the many schools that are using these research-intensive schools as models for "success." Put another way, NAE focus on the election of its members on the basis of individual engineering-research contributions provides an indirect, but tight, constraint on the changes urged by a number of individuals, study committees and boards, including those in the ASEE and NRC reports [1, 2] and those espoused by current NAE leaders [3, 4].

The dearth of prestigious, national-level, rewards and recognition for high-quality contributions to engineering education – particularly, election to membership in the NAE – is considered to be one the root causes for the slow and halting progress of systemic engineering education reform. The problem stems from the relatively low value placed on undergraduate engineering education by many engineer-researchers, and the institutions that profit from their contributions. It is likely that some academic institutions will not want to "waste" effort and political capital, as well as risk missing a possible increase in USNWR rankings, on candidates from a present-day "who cares" area with relatively low-payoff in terms of prestige and peer recognition.

Additionally, there are a number of special people in engineering education – they form a veritable "who's who" of individuals who have distinguished themselves by high-quality contributions in this area. The fact that educators of such high-caliber are not members of the NAE stands as a salient challenge to the credibility of the NAE re: the value the Academy, as a whole, places on high-quality contributions to engineering education. Most likely, such eminently distinguished engineering educators will not be considered "worthy" of NAE membership by the majority of electing NAE members so long as: 1) Noteworthy contributions to the field of engineering education are thought of as merely supplemental to the primary qualifications of: important contributions to engineering theory, practice, and literature, and/or demonstration of unusual accomplishments in the pioneering of new and developing fields of technology; and 2) Engineering education is not considered as a principal branch of engineering activity with an assigned NAE engineering category/section and associated peer-review committee.

It is understood that education is already in the NAE nomination and membership criteria, just as it is in all the Academic Faculty Codes. So, simply putting in writing that it is a valid reason to nominate and elect will likely do as much good within the NAE as it does with faculty merit criteria at engineering-school promotion and tenure committee meetings. That is why the second item is essential so as to help assure that engineering education receives significant attention from some of the best minds in the engineering community. Perhaps a few of these should, and would, make the dominant part of their contribution to engineering education. Also, there is something of value about significant contributions to the engineering literature, where appropriate. Perhaps it is not well known in the academic-scientific-research community that the ASEE Journal of Engineering Education and the IEEE Transactions on Engineering Education are peer reviewed and archived publications.

So long as the NAE continues to elect its members the way it does, it will perpetuate the status quo, or, as Roderick G. W. Chu put it: "*If you keep doing what you have always done, you're going to get what you always got*" [12]. Ernest Boyer also said it well: "*…the time has come to move beyond the tired old "teaching versus research debate" and give the familiar and honorable term "scholarship" a broader, more capricious meaning, one that brings legitimacy to the full scope of academic work*" [11, p 16]. All things considered, what seems to be required is some "out-of-the-box" thinking and doing.

III. AN OUTLINE FOR A PATH FORWARD

It would appear that the task before us is to enlighten the various stakeholders in engineering education. Specifically, we need to show that the (remarkably consistent) changes recommended by Wulf and Fisher, the ASEE and NRC reports [1-4], as well as other related reports and papers, are not only feasible, but that it is in the current and future self interest of our engineering schools to embrace the changes appropriate to the context of their institution, its student body, faculty, and objectives. The NAE can play a major role in this enlightenment by placing its imprimatur on the changes recommended in the ASEE Green and NRC BEEd reports and by providing unequivocal and visible demonstrations *"that the Academy attaches great value to creative work in engineering education and wishes to acknowledge and spread the best ideas*" [3]. Some suggested avenues of approach are as follows:

A. Academic Institution and Faculty Path

A primary objective of the 1998 Engineering Foundation Conference was to examine what were then thought to be some of the best undergraduate engineering programs [13]. This examination provided an outline for the development of several structural models that incorporated the requisites for implementing and maintaining "good" programs. A complementary set of models was added by Splitt [14]. The next step involves making it attractive for schools to commit themselves to change from what they do now to something approaching an appropriate one of the models. In view of increasing competition and advanced technology delivery systems, Splitt [14] argues that it is in the long-term-economic self interest of our engineering schools to cope with the upcoming shift in the engineering education marketplace by implementing programs that reflect change, such as those outlined in the NRC/BEEd Report. This may very well be one of those problems where anecdotal and inferential evidence is all that we will have; where once the shift in arrives in force, it will be too late for the schools to deal with it – the market will have already decided. Nevertheless, it is suggested that the NAE can play an important role via a substantive study of the economic threat to the future of our research-intensive engineering schools.

Achieving and maintaining the needed changes in academic culture is a long-term effort. It requires the identification, support, and nurturing of change agents in engineering schools across the country. A related issue appears to be maintaining sustained administrative support for change. Engineering deans cannot realistically mandate a culture change, but they can set a tone and use their limited discretionary funds to help assure that change is not stifled when it appears. Again, we need to assure that engineering education receives significant attention from some of the best minds in the engineering community. Those that make innovative undergraduate engineering education the dominant part of their contribution will do much to improve student retention and encourage graduate study, to the ultimate benefit of the academic research community. It is suggested that the subject of engineering-school enlightenment in these, and other areas such as student enrollment and retention, and practitioner job security, be considered as study topics for NAE working committees – including, with the study deliverables, a related list of actions that could be taken to catalyze change and continuous improvement.

B. ABET Related Path

Resistance to ABET oversight and accountability notwithstanding, the outcomes based structure of ABET EC 2000 appears to provide the key for change and for keeping the change fresh on a program-by-program basis. A strong, credible, and respected ABET organization can play an essential role in the realization of systemic engineering education reform. The NAE can facilitate the development of these attributes by not only working with ABET, but also by encouraging engineering schools to do so as well. Furthermore, NAE leaders can encourage the ASEE Engineering Dean's Council, engineering professional societies, and other appropriate groups to follow the 1995 NRC/BEEd Report recommendation to work cooperatively with ABET in its reassessment of accreditation criteria in accordance with the types of changes suggested in the report and implemented in response to current and future needs in engineering education. The NAE can also work to: 1) Determine better ways (than ABET-related) to stress (to engineering students) that environmental and other "non-technical" factors covered in the NRC/BEEd Report are very important to consider up front in engineering design and that engineers have an important social responsibility; and 2) Study ways and mechanisms aimed at the resolution of ABET-related issues and problems.

In the likely ongoing process of evaluating the relative priorities of NAE engineering education initiatives, consideration might be given to leveraging the NAE's connection with the ASEE Engineering Deans Council to encourage the Deans to express their ABET-related concerns and to offer ABET-free alternative solutions to introducing the changes recommended in the NRC BEEd Report at their engineering schools. If it is the view of an engineering school that utilizing ABET Criteria is not the best way to introduce these changes, they could be asked to provide their thoughts and suggestions as to better ways – and, to the specific ways their school would be willing to commit to an implementation schedule.

C. A Path for Electing Qualified Engineering Educators to the NAE

With reference to the discussion of academic resistance to electing qualified engineering educators to the NAE, NAE President Wulf has advised, via personal communications, that the new criteria have been adopted as stated in the following excerpt from the Wulf-Fisher paper [3]: "*First, we've reaffirmed that high-quality contributions to engineering education are a valid reason for election to the NAE. This criterion makes it clear that people's creativity and excellence in engineering education can be rewarded in the same ways as outstanding technological contributions*." This is an encouraging first step. However, as implied in the previous section, simply putting in writing that it is a valid reason to nominate and elect candidates for the NAE is a necessary, but not sufficient, condition to assure a sustainable election process for worthy candidates in engineering education.

Boyer's definition of scholarly activity [11, p 16] and the NRC BEEd Report's expanded working definition of scholarship [2, p 46], provide further rationale for recognizing engineering education as a principal branch of NAE engineering activity, and alignment of the NAE with this recognition as a priority activity. It would seem that this would be a straightforward approach to the resolution of the credibility problem, as well as the taking of a big step in addressing the larger problem of academic rewards and recognition. This move to inclusiveness would focus the attention of the academic community on the high value the NAE places on engineering education. It is the linchpin of an overall strategy aimed at breaking down the extant barriers to more rapid progress in engineering education reform and assuring the technical health of our nation.

IV. PROGNOSIS

The suggested action items outlined above can be summarized as follows: 1) Recognize engineering education as a principal branch of engineering activity and align the NAE with this recognition as a priority activity; 2) Encourage the development of a strong, credible, and respected ABET organization; and, 3) Conduct substantive studies aimed at problem identification/resolution and engineering-school enlightenment as to the long-term benefits, to the school and its ultimate customers, of implementing changes appropriate to the context of their institution, its student body, faculty, and objectives. So what might we expect in the way of outcomes?

Many billions of dollars have funded the mission shift of many of our engineering schools from teaching and service to research. Consequently, it is expected that consideration of the suggested NAE initiatives, particularly, the inclusion of engineering education as a principal branch of engineering activity, would be an emotionally wrenching issue and give rise to a tough debate. The debate should reveal how deeply the value placed on educational contributions by the NAE leadership has penetrated the majority of current NAE members, some of whom are part of the group of faculty members that have been hired and promoted primarily on the basis of their research strengths. These academic-engineering researchers will likely opt for exclusiveness and oppose a move toward inclusiveness. It will require a profound change in attitudes, demanding much more than statements by NAE leaders, to overcome what may very well be a deeply embedded culture of engineering-researcher elitism.

When speaking of the difficulty in responding to change at our colleges and universities, James Duderstadt provided insights that, to some degree, are applicable to change at the NAE: "*It may be necessary to drive an organization toward instability, toward chaos, in order to shift it from one paradigm to the next. Sometimes this happens naturally as external forces drive an organization into crisis, sometimes it results from the actions of a few revolutionaries, and sometimes it even happens through leadership, although as Machiavelli observed, it is rarely well received by those within the organization* [8, p 268].

To put the issue in perspective, one need consider lost-opportunity costs. Most likely, the suggested initiatives would have a ripple effect beyond measure – enabling the breakdown of extant barriers to engineering education reform. With so much to be gained in benefits and apparently nothing of real consequence to be lost, follow up on the suggested initiative would be well worth a serious and intensive effort. Absent a dedicated effort, it is very likely that the status quo will prevail, leaving engineering education reform to founder. However, there is reason for optimism. With appropriate education, management, care and the good will of those who have the means to influence the process, in due course opponents of change, defenders of the status quo, will be enlightened and proceed to act in their enlightened self interest. The NAE culture will change so that it will be possible for the NAE to become proactive in engineering education reform and for exemplary contributors to engineering education to be elected to the Academy on a sustainable basis. In turn, this will catalyze change in academe and accelerate the pace of systemic engineering education reform.

V. CONCLUSION

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 NAE 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 NAE, and a boon to engineering education reform/revitalization, if the NAE would work to implement the suggested initiatives. These initiatives could very well provide the breakthrough that, over time, would enable the widespread implementation of the changes needed in the 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. As stated in the epilogue of the NRC BEEd Report: "*The education of this nation's engineers deserves no less*" [2, p 55].

REFERENCES

1. American Society for Engineering Education Deans Council and Corporate Roundtable, *The Green Report: Engineering Education for a Changing World,* Washington, DC: American Society for Engineering Education, October 1994.
2. National Research Council's Board on Engineering Education (BEEd), *Engineering Education: Designing an Adaptive System*, National Research Council Report*,* Washington, DC: National Academy Press, 1995.

3. Wulf, William A. and Fisher, George M. C., "A Makeover for Engineering Education", *Issues in Science and Technology*, Spring 2002, <http://www.nap.edu/issues/18.3/p_wulf.html>, accessed January 6, 2003.
4. Wulf, William A., "The Urgency of Engineering Education Reform," Plenary Address, 2002 ASEE Annual Conference & Exposition, Montreal, Canada, June 17, 2002.
5. Prados, John W., "Action Agenda for Systemic Engineering Education Reform: Next Steps*," Proceedings of the 1998 Engineering Foundation Conference*, New York, New York: Engineering Foundation, pp. 1-13.
6. Katz, Stanley N., **"**The Pathbreaking, Fractionalized, Uncertain World of Knowledge," *The Chronicle of Higher Education*, September 20, 2002, p. B7.
7. National Research Council Panel on Undergraduate Education, Committee on the Education and Utilization of the Engineer, Commission on Engineering, *Engineering Education and Practice in the United States: Engineering Undergraduate Education*, Washington, D.C., National Academy Press, 1986.
8. Duderstadt, James J. J., *A University for the 21st Century*, University of Michigan Press, September 1999.
9. Kenny, Shirley Strum (Commission Chair), *Reinventing Undergraduate Education: A Blueprint for America's Research Universities*, The Boyer Commission on Educating Undergraduates in the Research University, Stony Brook, New York: The Carnegie Foundation for the Advancement of Teaching, 1998.
10. Kenny, Shirley Strum (Commission Chair), *Reinventing Undergraduate Education: Three Years After the Boyer Report*," The Boyer Commission Report on Educating Undergraduates in the Research University, Stony Brook, New York: The Carnegie Foundation for the Advancement of Teaching, 2002.
11. Splitt, Frank G., "Environmentally Smart Engineering Education: A Brief on a Paradigm in Progress," *Journal of Engineering Education*, October 2002, see page 3 of this trilogy.
12. Boyer, Ernest L., *Scholarship Reconsidered: Priorities of the Professoriate*, , Stony Brook, New York: Carnegie Foundation for the Advancement of Teaching, December 1990.
13. Chu, Roderick G. W., T*he Chronicle of Higher Education*, December 4, 1998. p. A32.
14. Ernst, Edward W., *Proceedings of the 1998 Engineering Foundation Conference*, *Preface,* New York, New York: Engineering Foundation.
15. Splitt, Frank G., "The Challenge to Change: On Realizing the New Paradigm for Engineering Educatio*n*," *Journal of Engineering Education*, April 2003, see page 7 of this trilogy.

AUTHOR'S BIOGRAPHY

Frank G. Splitt received a BSEE from the Fournier Institute of Technology in 1952 and an MS and Ph.D. in Electrical and Computer Engineering from Northwestern University in 1957 and 1963, respectively. He is the McCormick Faculty Fellow of Telecommunications, McCormick School of Engineering and Applied Science, Northwestern University and Vice President Emeritus of Educational and Environmental Initiatives, Nortel Networks. As a Director of the International Engineering Consortium (IEC), he chaired the IEC's Committee on the Future and currently chairs its Fellow Awards Committee. He was also a member of the Accreditation Board for Engineering and Technology (ABET) Industry Advisory Council, the Institute of Electrical and Electronic Engineers (IEEE) Educational Activities Board, and a member of the IEEE Corporate Recognitions Committee. His professional career covered research & development, marketing, administration, teaching, and public service. He has authored numerous technical papers, as well as articles on public affairs. He is a member of the American Society for Engineering Education, a Fellow of the IEC, a Life Fellow of the IEEE, and an Eminent Engineer of Tau Beta Pi. His interests involve research and planning for the future of Engineering Education and environmental conservation. He and his wife Judy reside in Mt. Prospect, Illinois and in Star Lake, Wisconsin.

Address: McCormick School of Engineering and Applied Science, Northwestern University, Evanston, Illinois 60208-3100; telephone: (+1) 847-253-1511; e-mail: fgsplitt@ece.northwestern.edu;
URL: www.ece.northwestern.edu/EXTERNAL/Splitt/