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Engineering Education Reform: Signs of Progress

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

BACKGROUND AND INTRODUCTION

THIS BRIEF is rooted in addresses delivered at a University-Industry Colloquium in 1991and at the Green Engineering Conference in July 2001 [1, 2]. Later in 2001, work began on a proposal to close the environmental literacy gap that exists in most of our nation's engineering programs [3]. The proposal effort provided valuable insights and eventually led to a renewed campaign for systemic engineering education reform [4, 5] that must address the following frequently asked questions:

- Why is the large change such as that implied by 'systemic engineering education reform' needed?
- Why can't incremental change make the required changes on an appropriate time scale?
- Why do we need to recognize leadership and systemic change in engineering education now?

Answers to these questions—highlighted in references 4 and 5—continue to be critical to an understanding of the need. Above all, engineering graduates need to be much better prepared for the 21st-century engineering workplace. According to Rosalind Williams [6]:

> The convergence of technological and liberal-arts education is a deep, long-term and irreversible trend. Students need to be prepared for life in a world where technological, scientific, humanistic and social issues are all mixed together.

Numerous articles, papers, books, workshops and conference proceedings have made a compelling case for systemic engineering education reform. Among these are the recent calls for change by the National Academy of Engineering (NAE) leadership [7]. Notwithstanding the numerous earlier calls for action, increasing competition from alternate service providers, as well as student-pipeline and job-security issues, resistance to change continues unabated. Nevertheless, there have been recent signs of progress, particularly with respect to environmental and sustainability considerations. All of this formed the basis for an invitation to provide a keynote address to the engineers, scientists and educators attending the Quantum Sensing and Nanophotonic Devices Conference at the 2004 SPIE Integrated Optoelectronic Devices Symposium.

THE IMPORTANCE OF SUSTAINABLE DEVELOPMENT

But why should there be emphasis on environmental considerations and sustainable development? Here's why. Evidence abounds that we are reaching the carrying capacity of the earth—engaging in deficit spending if you will [8]. The amount of crops, animals and other biomatter we extract from the earth each year exceeds what the earth can replace by an estimated 20%. Additionally, signs of climate change are precursors of things to come. What's more, global industrialization and the new technologies of the 20th century have helped to stretch the capacities of our finite natural system to precarious levels. Taken together, this evidence reflects a fraying web of life.

Numerous organizations and efforts have cited the importance of sustainable development. For example, the National Science Board began its report [9], *Environmental Science and Engineering for the 21st Century*, with the statement, 'Within the broad portfolio of science and engineering for the new century, the environment is emerging as a vigorous, essential and central focus . . . The environment is no longer simply a background against which research is conducted, but rather

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the prime target for increased understanding' Over the years, the NAE 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.

Amory B. Lovins, the CEO of Research at the Rocky Mountain Institute, is a master of innovation in energy efficiency [3]. He and his co-authors expand on the subject in their book [10], *Natural Capitalism*: *Creating the Next Industrial Revolution*, claiming 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. They go on to 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. They also provide examples and 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. Clearly, engineering and its technological derivatives can help remedy environmentally related problems. However, although sustainable development and natural capitalism can work to reverse ominous trends, we are often still wedded to the notion that environmental conservation and economic development are the 'players' in a zero-sum game. So the well-being of future generations will depend to a large extent on how we educate our future engineers . . . engineers who can transcend this false notion. These engineers will be a new breed—developing and using sustainable technology, benign manufacturing processes and an expanded array of environmental assessment tools that will simultaneously support and maintain both a healthy environment and economy.

THE IMPEDIMENTS TO CHANGE

Experience teaches that achieving change via engineering education reform presents a formidable challenge. This should come as no surprise given academe's bias toward preservation of the status quo. It is part of the overarching challenge of change, faced by universities and colleges throughout our nation, as described by Jim Duderstadt in his comprehensive analysis of the issues and the need for a new paradigm [11].

The integration of new concepts and materials 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 [12]. So what's the dilemma? Simply stated, it is the fact that educational products in this vital area do not represent the coin of today's academic realm. Put another way, they do not fit the present-day rewards and recognition systems that are driven by publications and research funding. According to John Ehrenfeld [13], 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. And that's not all.

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. There has been strong resistance to embedding additional requirements in the ABET criteria. Tenure-protected faculty, along with like-minded deans, associate deans and department heads, could rise as a major obstruction to change—serving as endangered species of academic foxes guarding the engineering-school henhouse. Perhaps, the greatest impediments to change are inertia and time . . . time to work on the important, as opposed to the day-to-day, time-consuming, 'urgent.'

SIGNS OF PROGRESS

There are signs of progress—encompassing the work at ABET and pacesetting schools of engineering, the initiation of the Campaign for Systemic Engineering Education Reform (a.k.a. the SEER Campaign), faculty work on program evolution, and other important related efforts. There follows a brief summary of 'what's going on'.

ABET closing the environmental literacy gap

In the early 1990s, ABET's first Industry Advisory Council called upon ABET to bring about a major paradigm shift in engineering education. We recommended a set of Accreditation Process Principles, Concepts and Supporting Strategies that later helped form the basis for the Programs Outcomes and Assessment component of ABET Engineering Criteria 2000 (ABET EC 2000). The Principles called for the 'understanding of and work toward sustainable development, safety and environmental impact'. The wording of the Accreditation Process Principles was subsequently generalized so the present criteria do not reflect the emphasis that we placed on environmental considerations. Nevertheless, the ABET EC 2000 criteria provide a mechanism that can be used to drive as well as enable change in this and other areas.

ABET EC 2000's present criteria are open to an interpretation that can permit an environmental

literacy gap to exist in our engineering programs and disciplines [3]. An effort to close the environmental-literacy gap was initiated in the fall of 2001 [3]. The National Council for Science and the Environment (NCSE), Northwestern University, Virginia Tech and the Accreditation Policy Council of the IEEE Educational Activities Board endorsed a related proposal while personal endorsements and commentaries came from academe and industry [14].

ABET Engineering Criteria have now been marked up with revisions, proposed by the IEEE, that were accepted by the ABET Board of Directors at their meeting this past November. If the revised Engineering Criteria are approved on second reading at the Board's fall meeting in 2004 they will be applicable for visits commencing in fall 2005. Engineering programs must then demonstrate that their students attain an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability, as well as demonstrate the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context.

Looking further to the future, resistance to ABET oversight and accountability notwithstanding, the outcomes based structure of ABET EC 2000, coupled with its call for greater documented involvement of engineering education 'constituencies', provides a 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 ABET Industry Advisory Council can support industry representatives on the various ABET committees and commissions—identifying what is needed and insisting that change occurs.

Pacesetting programs

It has been suggested that the 4-year, undergraduate engineering education is a dinosaur and that Draconian action is required—starting with a clean slate by eliminating all specialized engineering majors, particularly at the undergraduate level—so as to stimulate debate and thought to shake up and transform engineering education. Although this may very well be true in theory, I believe that a 'flash-cut' approach is undoable. Change will most likely occur incrementally. A number of engineering schools have made significant changes and have developed innovative approaches in their undergraduate programs [15]. If undergraduate engineering education is indeed a dinosaur, then Northwestern's *Engineering First*, Drexel's E4 Program along with the updated engineering education programs at Harvey Mudd, WPI, Notre Dame, UC-Boulder and Rose-Hulman are a few examples of excellent transitioning programs—points of light—that can illuminate paths to the future. These pacesetting programs have not only proved to be doable, but they can be made even better. 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.

The SEER Campaign: an evolving story

In a nutshell, engineering education reform is all about educating the stakeholders and motivating them to play their respective roles. To this end, the International Engineering Consortium published a trilogy on engineering education reform as a service to academia, government and industry. Its widespread distribution has been facilitated via publication by the ASEE and the IEEE [16], as well as by Website access and distribution at various conferences and workshops. The *Trilogy* is now serving as a white paper for the SEER Campaign. An article in *THE BENT* of Tau Beta Pi [5], encapsulated important aspects of the *Trilogy*—providing an introduction to the SEER Campaign to some 90,000 members of the Tau Beta Pi engineering honor society. A plenary address at an NSF Engineering Education Coalition's Conference [17] focused on the multiple time-related dimensions of reform efforts while a brief [18], covering work on reform in intercollegiate athletics and engineering education, was released for publication December 2003.

Discussion of SEER Campaign aims has been planned for the various stakeholders in the future of engineering education—including academic administrators, faculty, students, parents, professional societies, as well as industry and government leaders. This distribution represents a crosscutting, bottom-up/top-down approach to promoting debate of the issues surrounding systemic engineering education reform. Thus far, contact has been made with over sixty institutions, organizations and professional societies.

Program evolution

Work by faculty is progressing in various disciplines to resolve the problem of how best to address the challenges of preparing students for leadership and success. They are seeking to determine what to include in an already full curriculum as well as in time-expanded engineering programs. For example, this past April, Linda Vanasupa, the chair of the Academic Affairs Committee of the Materials Science and Engineering Society presented a conference paper that addressed the challenge of adjusting materials science and engineering curricula to integrate environmental concepts [19]. Also, for about the past twenty years, it has been contended that the proper education of professionals requires a pre-professional baccalaureate program. This pre-professional program would be followed by a practice-oriented Master of Engineering degree program, possibly as only a first step

in an evolution over time to the Doctor of Engineering as the only accredited engineering degree. Work is heating up in this area as well [20–23].

The NAE's four-part strategy

The NAE announced the establishment of a Center for the Advancement of Scholarship in Engineering Education (CASEE), with Norman Fortenberry as Director, in September 2002—capping a commendable effort to raise the prominence and effectiveness of engineering education. One of the purposes of CASEE is to provide the education research base that will support systemic reform of engineering education. During the 1999–2001 period, the NAE established a Committee on Engineering Education, expanded its criteria for membership to more fully recognize contributions to engineering education, and established the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education, a $500,000 award to emphasize the importance of education to the future of engineering.

The expansion of the criteria for NAE membership is a most encouraging first step. In February 2004, the NAE announced Drexel Professor Eli Fromm's election to membership *with a citation specific to education*. Hopefully, this breakthrough event will allow other deserving candidates who have made outstanding contributions to engineering education to follow in Dr. Fromm's footsteps. It has been suggested that the NAE give consideration to recognition of engineering education as a principal branch of NAE engineering activity—assuring a sustainable election process for worthy candidates, thus focusing the attention of the academic community on the high value the NAE places on engineering education [16]. It has also been suggested that the NAE help facilitate the development of a strong, credible and respected ABET—encouraging the ASEE Engineering Dean's Council, engineering professional societies and other appropriate groups to follow the NRC recommendation to work with ABET in its reassessment of accreditation criteria.

The NSF coalitions and new centers

Through cross-coalition collaboration, the NSF Engineering Education Coalitions developed intellectual exchange and resource links among undergraduate engineering programs. Annual *Share the Future* conferences were initiated in 2000. These conference workshops have centered on topics relevant to NSF Coalition goals—providing the extended engineering education community an opportunity to share in the research findings and experiences of the Coalitions.

The NSF-sponsored Center for the Advancement of Engineering Education (CAEE) opened in January 2003 with an initial five years of support. The University of Washington serves as the director of the Center that also includes Stanford University, Howard University and Colorado School of Mines. CAEE will pose and answer basic questions about how students learn engineering, how to support faculty learning about and adopting more advanced teaching methods, and how to foster the development of future generations of engineering education researchers, as well as leaders and change agents in engineering education.

The NSF also announced the Center for the Integration of Research, Teaching and Learning (CIRTL). A five-year grant will allow CIRTL to focus on questions surrounding Science, Technology, Engineering and Mathematics (STEM) Ph.D. education as well as the integration of teaching into this education. CIRTL is a collaboration of STEM faculty and education researchers at the University of Wisconsin-Madison, Michigan State University and Pennsylvania State University that will work to develop a future national STEM faculty—enabling all students to achieve STEM literacy, teaching that enhances recruitment into STEM careers, and leadership that ensures the continued advance of STEM education. CIRTL will treat the improvement in teaching as a research problem and may very well change the way science and engineering are taught.

Some important related efforts

- *Professional Societies.* The work done by the Technical and Educational Activities Committees of the various Engineering Societies has been encouraging. The civil engineering profession is taking a leadership role. In 2001, the American Society of Civil Engineers (ASCE) approved a policy stating that ASCE supports the concept of the Master's degree or equivalent as a prerequisite for licensure and the practice of civil engineering at a professional level. All 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 as well as to professional-level degrees.
- *Engineers Forum on Sustainability*. This forum is co-sponsored by the American Society of Civil Engineers (ASCE), the American Society for Engineering Education (ASEE), and the American Institute of Chemical Engineers (AICE). The mission of the Forum is to help promote the principles and practice of sustainability via interdisciplinary discussion and the exchange of information; identifying and distributing information on engineering education programs that incorporate sustainability; encouraging practicing engineers to apply the principles of sustainability and participate in sustainability programs and activities at local, regional and national levels, and keeping abreast of and sharing information on international developments that can contribute to global sustainability.
- *EPA P3 Award Program.* This program is focused on people, prosperity and the planet.

It is a national competition that will provide grants of up to $10,000 for as many as 50 teams of students and research, design and development sustainability-based projects [23]. Its aim is to aid in the training of the next generation of scientists and engineers who will need to meet the challenge of developing new products and processes while at the same time protecting the environment and conserving natural resources; see the EPA Website at www.epa.gov for details.

- *The Twelve Principles of Green Engineering*. There is a growing focus on the twelve principles espoused by Paul Anastas and Julie Zimmerman [24, 25]. As explained in the cited references, the principles (listed in the Appendix) provide a framework for designing new materials, products, processes and systems that are benign to human health and the environment—moving beyond baseline engineering specifications for quality and safety to consider life-cycle environmental, economic and social factors as well.

CONCLUDING REMARKS

There can be many paths leading to the future of engineering education depending upon the starting point, e.g., large research universities vs. small and medium sized non-Ph.D. granting colleges/universities and early adopters vs. the laggards in adopting the new paradigm for engineering education. The fact that there is no 'one-size-fits-all' transition paradigm, contributes to the challenge to change. Nonetheless, pacesetting engineering schools, engineering department heads associations, societies and organizations, as well as individual faculty members, government and business leaders can play significant roles in bringing about reform.

It is expected that commonplace practice of sustainable development and business practice will evolve over time. The key to this evolution is expected to be the growing awareness by the financial and investment communities of the intrinsic value of achieving maximum long-term economic gain and minimum overall environmental impact as 'blueprinted' in Lovin's *Natural Capitalism*. Businesses will then exert an ever-increasing demand for engineering graduates conversant with environmental issues and economics and, most importantly, engineers skilled in systems thinking and in related design and manufacturing practices via application of the *Twelve Principles of Green Engineering*. ABET can play a vital role in this area. However, it will not be easy, and, to be sure, there are no guarantees—only time will tell the outcome.

Finally, 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 Academy, and a boon to engineering education reform, if it would work to help enable the widespread implementation of the changes needed in our engineering education system—helping to motivate and mobilize the stakeholders in engineering education to address the challenge to change. The stakeholders—academic administrators and faculty members, ABET, government policy makers and agency program managers, and professional society as well as industry leaders—should see this as a clarion call to action on their parts as well. Our nation's future engineers deserve no less than an affirmative as well as enthusiastic response.

REFERENCES

1. F. G. Splitt, Creating our common future—reflections on the 4 Es: Environment, Education, Energy and Economics, *THE BENT* of Tau Beta Pi, **83**, 1992, pp. 29–32.
2. F. G. Splitt, An odyssey of educational and environmental initiatives: from national information infrastructure to the fate of our inland lakes and ecoefficient design, Keynote Address, *Virginia Tech and EPA Sponsored Green Engineering Conference on Sustainable and Environmentally Conscious Engineering*, Roanoke, VA, (2001).
3. F. G. Splitt, Environmentally smart engineering education: a brief on a paradigm in progress, *J. Eng. Educ.*, **91**, 2002, pp. 447–450.
4. F. G. Splitt, The challenge to change: on realizing the new paradigm for engineering education, *J. Eng. Educ.*, **92**, 2003, pp. 181–187.
5. F. G. Splitt, Systemic engineering education reform: a grand challenge, *THE BENT* of Tau Beta Pi, **94**, 2003, pp. 29–34.
6. R. Williams, *Retooling: A Historian Confronts Technological Change*, MIT Press (2002) p. 82.
7. W. A. Wulf and G. M. C Fisher, A makeover for engineering education, *Issues in Science and Technology*, (2002).
8. *World Resources 2001–2002: People and Ecosystems, The Fraying Web of Life*, a report by the United Nations Development Programme, The United Nations Environment Programme, the World Bank, and the World Resources Institute, World Resources Institute, Washington, DC (2000).
9. E. M. Kelly 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 (2000).

10. P. Hawken, A. Lovins and L. Hunter Lovins, *Natural Capitalism: Creating the Next Industrial Revolution*, Rocky Mountain Institute (1999).
11. J. J. Duderstadt, *A University for the 21st Century*, University of Michigan Press (1999).
12. C. M. Christensen., *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Harvard Business School Press, Boston, MA, (1997).
13. J. R. Ehrenfeld, Industrial ecology and design for the environment: the role of universities, in *The Greening of Industrial Ecosystems*, pp. 228–240, National Academy Press, Washington, DC (1994).
14. http://www.ece.northwestern.edu/EXTERNAL/Splitt/ABETEndAndPersComm.doc
15. http://www.ece.northwestern.edu/EXTERNAL/Splitt/SplittABriefonSomeParadigmShifting Schools.doc
16. F. G. Splitt, *Engineering Education Reform: A Trilogy*, International Engineering Consortium, Chicago, IL, (2002); (published as a three-part series in the April, August and November issues of the *ASEE-IEEE Joint Newsletter, The Interface* (2003).
17. F. G. Splitt, Systemic engineering education reform: it's about time, plenary address, *NSF Share the Future IV Conference*, (2003).
18. F. G. Splitt, *Reclaiming Academic Primacy in Higher Education: A Brief on Working for Reform in Intercollegiate Athletics and Engineering Education*, IEC Publications (2003).
19. L. Vanasupa and F. G. Splitt, Curricula for a sustainable future: a proposal for integrating environmental concepts into our curricula. Presented at the *Annual Conference of the Material Research Society*, April 13, 2004.
20. B. Friedland and P. Dorato, A case for the doctor of engineering as a first professional degree, *Engineering Education* (1987).
21. P. Dorato and W. Lyons, Master of engineering: past, present, future, *Proc. 2002 ASEE Annual Conference & Exposition*, Session 2793 (2002).
22. J. M. Tien, *Time to Think about a Master's of Engineering*, The IEEE Institute (2003).
23. R. F. Vaz and J. A. Orr, ECE as a pre-professional undergraduate program, *IEEE Trans. Education* (2003).
24. EPA launches engineering award, *Chemical & Engineering News*, January 5, 2004, p. 26.
25. P. T. Anastas and J. Zimmerman, Design through the 12 principles of green engineering, *Environmental Science and Technology*, **37**(5), 2003, pp. 94A–101A.
26. W. McDonough, M. Braungart, P. T.Anastas and J. B. Zimmerman, Applying the principles of green engineering to cradle-to-cradle design. *Environmental Science and Technology*, **37**(23), 2003, pp. 434A–441A.

Note: References 1–5, 14, 15 and 18 can be viewed at: www.ece.northwestern.edu/EXTERNAL/Splitt/

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APPENDIX

The twelve principles of green engineering

1. Designers need to strive to ensure that all material and energy inputs and outputs are as inherently non-hazardous as possible.
2. It is better to prevent waste than to treat or clean up waste after it is formed.
3. Separation and purification operations should be designed to minimize energy consumption and materials use.
4. Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. Products, processes and systems should be 'output pulled' rather than 'input pushed' through the use of energy and materials.
6. Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. Targeted durability, not immortality, should be a design goal.
8. Design for unnecessary capacity or capability (e.g., 'one size fits all') solutions should be considered a design flaw.

9. Material diversity in multi-component products should be minimized to promote disassembly and value retention.
10. Design of products, processes and systems must include integration and interconnectivity with available energy and materials flows.
11. Products, processes and systems should be designed for performance in a commercial 'afterlife.'
12. Material and energy inputs should be renewable rather than depleting.