AC 2010-34: CHALLENGES AND RESPONSES OVER A QUARTER-CENTURY OF MANUFACTURING EDUCATION

David Wells, North Dakota State University

David L. Wells has been Professor of Industrial and Manufacturing Engineering at North Dakota State University since January 2000. He teaches undergraduate and graduate courses in process engineering and production engineering systems design and in product innovation and entrepreneurialism. His instruction is characterized by heavy reliance upon project-based, design-centric learning. Course projects are drawn from real industrial applications with real industrial constraints, often interactive with a corporate sponsor. Students are challenged to design effective and efficient part manufacturing methods and complete production systems for commercial and industrial products. The common theme for students is mastering process, production system and enterprise design procedures that are applicable to any product in any industry. Graduates have been successful in manufacturing enterprises that produce virtually every type of product -- literally, from spacecraft to foodstuffs. In addition to traditional courses, Dr. Wells leads innovation teams in two engineering venues: product realization and transforming laboratory research into commercial products.

Dr. Wells' active research lies in orthopedic implants, micro-assembly, micro-machining, circuit board process engineering, printed electronics, applications of RFID technologies and manufacturing engineering pedagogy. Through his research, Dr. Wells has supervised the completion of twelve graduate degrees in the past six years. His publication history includes nearly seventy print publications and over forty invited presentations. He has addressed professional audiences in Ukraine, Japan, India, Brazil, Peru, Mexico and Canada, as well as in many United States venues. For many years, he has been active in the national leadership of Society of Manufacturing Engineers, American Society for Engineering Education, and ABET. Over the past twenty-six years, he has been a central figure in the design, development and articulation of curricula for educating manufacturing engineers in the United States and in selected off-shore venues. He also participates in Surface Mount Technology Association and Institute of Electrical and Electronics Engineers.

Prior to joining NDSU, Dr. Wells held manufacturing engineering and management positions in energy, aerospace, commercial sheet metal and automotive industries for twenty-six years. He also held a faculty position at University of Cincinnati for fifteen years, including thirteen years as chair of a department of some five hundred student head-count. He has also served as an academic dean in an experimental manufacturing engineering education program at Focus: HOPE (Detroit, Michigan) and as chair of the IME Department at NDSU. Dr. Wells is a certified manufacturing engineer and earned the BS and MS in Mechanical Engineering from Stanford University and the PhD in Engineering Management from the Missouri University of Science and Technology.

Challenges and Responses over a Quarter-Century of Manufacturing Education

Abstract: Over the quarter-century that has encompassed the life of the ASEE Manufacturing Division, education in manufacturing engineering and manufacturing engineering technology has faced more-or-less continuous challenge. It has always been difficult to convey the excitement and fulfillment of a manufacturing engineering career to young students -- and to the choice as an undergraduate major. It has always been difficult to make the case for the value proposition of expensive laboratories with university administrators. It has always been difficult to forge and maintain meaningful and effective linkages between campus and industry. Over the years, these challenges have been framed to reflect the crucial focus of the time -- of a particular year. At several key points in the past quarter-century, the manufacturing education community has come together to craft a useful response to the challenge-of-the-year. Many of these responses have become bedrock for education in the manufacturing engineering discipline. As the Manufacturing Division enters its second quarter-century, it is relevant to reflect upon the challenge-response cycle and, through that lens, to peer into the uncertain future. Yet again in 2010, manufacturing education faces substantive challenge. Once more, responses of depth and wisdom are needed. This paper will review three of the defining challenges of the past quarter-century and the responses that emerged. It will conclude with a view of current challenges and a suggestion for a path towards effective response.

Perspective: The ASEE Manufacturing Division celebrates its twenty-fifth anniversary year in 2010. The first annual conference with divisional status for our group was in 1986 at Cincinnati, and it is fitting that the twenty-five-year milestone is being observed just down the Ohio River in Louisville. Whilst we are celebrating the milestone, we should also remain cognizant of the roots of divisional status that were planted some five years earlier in Southern California, when the Constituent Committee was first formed.

Amidst the plethora of questions and alarums that have claimed attention of manufacturing educators over the past quarter-century and more, three primary challenges can be singled out as the encompassing issues. The first of these great issues is the definition of a body of knowledge for manufacturing engineering -- and of a curriculum to convey such knowledge to undergraduate students. The second primary challenge was the crafting of an articulated differentiation in terms of outcome objectives between and amongst the various educational degree levels that contribute to the professional discipline. The third great challenge has been the crafting of a strategic framework that enables individual programs to incorporate newly-emerging transformational technologies into a cohesive corpus of manufacturing engineering.

These great issues have been accompanied by continual concerns about the identity, health and vitality of the manufacturing engineering profession. Enrollments and the recruiting of young students into manufacturing engineering majors have been matters of substantial concern for at least three decades. The dialogue in 2010 still sounds remarkably like that in 1980; persuading bright youngsters to enter the challenging world of manufacturing engineering has been a hard sell throughout this entire period. In parallel, the struggle to equip and maintain modern teaching laboratories has changed little over three decades. Perhaps more so than most engineering disciplines, manufacturing laboratories are expensive of both space and equipment,

and persuading the university hierarchy of the need for investment has always been akin to mastering an arcane foreign language. Likewise, the connectivity of campus and factory has been discussed and debated in more or less constant terminology for several decades. Almost unchanged for thirty years, industry observers focus on their short-term needs and chide the academy for not having better technical foresight than their industrial counterparts. Conversely, while striving to be responsive to changing skill-set needs, educators wonder at the inconsistency and superficiality of industry support for the grooming of next generations of manufacturing engineers.

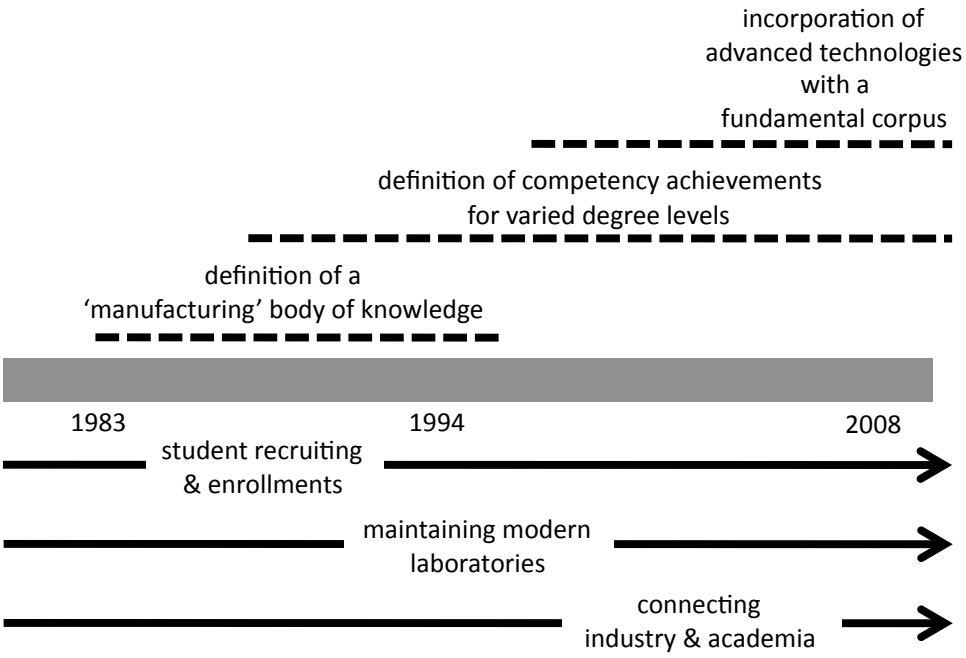

Figure 1: Challenges, Achievements and Persistent Problems in Manufacturing Education

It is suggested that the issues of recruiting and enrollments, of laboratories and teaching resources, of university-industry connectivity are symptoms of the larger issues identified above. The philosophical question that echoes throughout the three great issues is one of identity. What is "manufacturing engineering"? What is the inviolable persona of the professional organization that bears this title? What are the mutual responsibilities and dependencies between education and industrial practice? It is postulated that if these questions were to be answered clearly and without ambiguity, effective responses would be forthcoming to the great issues and to the nagging symptomatic problems. Likewise, it is further posited that continuance of this "great identity debate" is the causal source of the persistency of symptomatic challenges.

At this point, readers should rest easily for the nonce. This paper will not become a polemic screed on philosophical issues. Those worthy questions are left to another venue in another time. Nor will this paper address the persistent problems of student numbers, teaching resources and academic-industrial interaction. Those are matters of perspective, lurking in the background for

the following discussion on the three great challenges of the past thirty years and the responses observed thereto.

1983: The issue of a distinctive curricular identity for manufacturing engineering was first openly and cohesively articulated in the early 1980's. The founding of the Manufacturing Constituent Committee at the ASEE conference at Southern California in 1981 was one of the critical milestones. Another occurred at the ASEE conference in Salt Lake City in 1983, when over coffee during a break in the sessions, the notion of a workshop to explore curricular identity was first broached. The question formulated at that time was as direct as it was simple: "If you want to teach someone to be a manufacturing engineer, what do you teach?" The underlying, and more crucial, question concerned the crafting of a unique identity for 'manufacturing engineering', as distinct and differentiated from our brethren in mechanical, industrial and other engineering disciplines.

The immediate response was the organization of a workshop under the sponsorship of the Society of Manufacturing Engineers. This was a by-invitation-only event, held in the southern Ohio state park at Hueston Woods in the Summer of 1985. From this came a slim report, entitled *"Technical Education in Advanced Manufacturing"*, also known as the *TEAM Report*, that served as the first broadly-based reference explicitly intended and written for curricular guidance to manufacturing education programs.[1] It is worth noting that this effort was focused on manufacturing engineering technology and included explicitly differentiated responses for associate and baccalaureate degree levels.

This workshop was followed by a much larger SME event, still by invitation, in Southfield, Michigan in 1989 -- *Curricula 2000*.[2] Whereas *TEAM* had addressed rather general topical headings, *C2000* attempted to provide detailed course outlines for the wide variety of subject matter that was recommended for curricula in manufacturing engineering and manufacturing engineering technology. The primary threads for a manufacturing curriculum established in *TEAM* and in *C2000* became, with very little refinement, the outline for program guidance that has been often revalidated in subsequent years.[1,2]

design for production
materials
manufacturing processes
manufacturing systems & automation
controls
manufacturing management, productivity & quality
liberal studies
capstone experience

Figure 2: The Core Manufacturing Knowledge Stems from *Curricula 2000* [2]

Leading up to *C2000*, SME had also sponsored a hybrid invitation-open registration event in the previous year at Cleveland that focused attention on essential issues surrounding the

international character of manufacturing -- and of manufacturing engineering. One of the landmark curricular concepts for manufacturing education originated in this venue -- the distinction between the technology of manufacturing that is product- and process-specific and the infrastructure of manufacturing that is applicable to all products and all processes.[3]

Throughout the decade of the 1980's, the ASEE Manufacturing Division grew in membership and in scope of professional sessions sponsored at annual conferences. The Division also established a certain cachet of elegance overlaid on hard technological foundations. The Division awards banquets were formal -- black tie (or at least dark business suits) for gentlemen and cocktail dresses for ladies -- and held in venues characterized by both charm and uniqueness. The very first divisional banquet was held in a charming art deco hotel, with the cocktail hour and dinner accompanied by a string quartet and an after dinner program that included dancing to a live orchestra, as well as the usual verbalized component. There was a deeper purpose behind the banquet formality and eccentricity. Those trappings served to bring the new Division into clear vision within ASEE and to offer a tacit message that manufacturing had transformed from the dirt and grime of old silent movies into an era of sophistication and, even, elegance.

1994: The public reports emanating from the three SME events of 1985, 1988 and 1989 served the manufacturing education community admirably for a number of years. During this same time period, SME also published the seminal "*Countdown to the Future: The Manufacturing Engineer in the 21st Century"* (a.k.a. *Profile 21*) in 1988.[4] Likewise, in the late years of the decade, the outcomes movement began to take hold within both TAC and EAC of ABET, and SME responded with other workshops that created the first program criteria to focus on outcomes, rather than on curricular course content -- for both manufacturing engineering and manufacturing engineering technology.[5,6] The summation of these documents created a solid core and sturdy foundation for education in manufacturing engineering that has stood the tests of time. The guidance contained in those documents has remained valid for the succeeding decades.

Through the late 1980's and early 1990's, the long courtship between ASEE Manufacturing Division and SME matured into an effective and mutually beneficial partnership. This close association has continued and grown in both breadth and depth up to the present time and is one of the critically important assets for manufacturing education.

By the early 1990's, much experience and feedback had been accumulated from the SME reports of the 1980's and the companion dialogue in Manufacturing Division sessions at succeeding ASEE conferences. One of the most noticeable matters related to the differentiation and interaction between the various degree paths to professional careers in manufacturing. In parallel, the influences of *Profile 21* and the ABET outcomes initiative suggested that curricular prescription should give way to a defining of goals and outcomes.

Two questions came to be framed that defined the second of the great challenges of the past three decades -- to wit: to articulate the connectivity of manufacturing education at associate, baccalaureate and graduate levels and to define the five interrelated degree paths in terms of their outcomes. These were the focus for another by-invitation-only SME-sponsored workshop held

in the Spring of 1994 in Orlando -- the *Curricula 2002 Workshop*.[7] The *C2002* proceedings became the first volume in the landmark series, *Manufacturing Education for the 21st Century*, that eventually included an international compendium of manufacturing engineering education models, proceedings of two international conferences and the first edition of the *Manufacturing Education Plan*, that was to drive the agenda for the Manufacturing Engineering Education Foundation for the next decade.[7,8,9,10,11]

Manufacturing Engineering Technology	**Manufacturing Engineering**
Associate	
Bachelor	Bachelor
Master	Master

Figure 3: Five Degree Levels for Manufacturing Education as Considered in *Curricula 2002* [7]

The antecedents of *C2002* focused on prescription of courses to be included in manufacturing education programs and on detailed descriptions of suggested course content. *C2002* did not repeat that approach. Instead, the 1994 workshop articulated each of the five modes of manufacturing education in terms of the proficiencies that should result. The guidance offered from *C2002* included two further elements that have proven as durable as the famous *Profile 21* breadth-versus-depth portrayal of the manufacturing engineering discipline.

First, it was clearly articulated that the differences in degree level in manufacturing professional education are mostly a matter of theoretical foundation and depth-of-learning. Professional proficiencies of, say, a BS graduate and an MS graduate should not be differentiated by mastery of a different set of topics, but rather by the depth of that mastery and the strength of theoretical foundation that permits extrapolation to new technological content. This provides a perspective for curricular design in university programs -- and for effective utilization of new graduates by industrial firms.

The second timeless touchstone was a simple definition of "manufacturing" that offers endless opportunity for innovation in curricula, for close association between academic programs and industry groups, and for burnishing a robust public image of the professional discipline of manufacturing engineering. It was concluded by the *C2002* conferees that … Manufacturing occurs when a material (of any type) is modified (in any way) so as to add value.[7]

During the first dozen years of the ASEE Manufacturing Division history, the principal focus of manufacturing educators was the definition, refinement and validation of educational objectives and curricular content of engineering programs that are uniquely 'manufacturing' in nature. The primary threads of manufacturing engineering were re-examined and re-analyzed many times

over -- and finally emerged through the repeated crucibles of *TEAM*, *C2000*, and *C2002*. It can be concluded that these knowledge stems are the timeless pillars of the discipline.

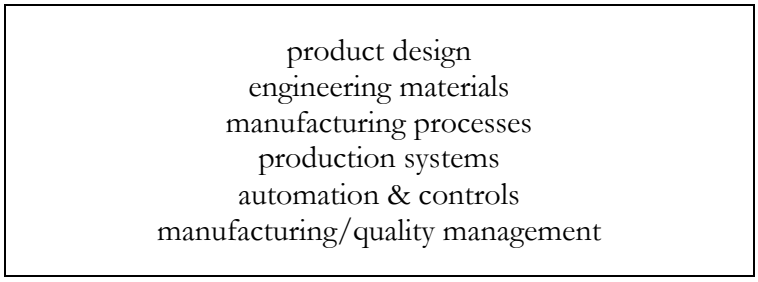

Figure 4: Refined Knowledge Stems of Manufacturing Engineering [1,2,7]

2008: The events in the *Manufacturing Education for the 21st Century* series continued through 1998, producing five volumes in all.[7,8,9,10,11] While pockets of substantive change in the concept and presentation of a 'manufacturing engineering' curriculum emerged, the overall landscape did not shift as substantially as the promise of *C2002* and its companion events seemed to presage. During the ensuing decade, no widely applicable solutions emerged to the persistent problems of the discipline.

Substantive challenges that touch the fundamental integrity of 'manufacturing engineering' as a definable discipline arose in slightly new form through the decade following the conclusion of the *21st Century* series. The on-going identity crisis within SME intensified, largely due to a re-echoing of questions from three decades earlier in the broader socio-political environment about the entire relevance of manufacturing as a valid social and economic influence and of manufacturing engineering as a viable discipline.[12] The pre-occupation of industry with methods for managing manufacturing technologies came to obscure the visibility within SME of the basic nature of manufacturing as the collective applied sciences of materials modification -- leading to the effective and efficient production of products.

A small movement of very large portent emerged in response, wherein the essential position of 'products' in the nature of 'manufacturing' was openly named as a critical part of the discipline.[13,14] Competencies in 'product engineering' had long been identified as critical in program accreditation criteria, as well as in central pillars of the discipline, but had been little emphasized in curricula.[6,7] It was (and is) posited that openly and purposely orienting manufacturing engineering as the central engine of product creation will be a positive influence is addressing the long-standing, persistent problems that have beset the discipline for thirty-plus years. A new program title of 'Product Design and Manufacturing Engineering' was created, with a curriculum that purposely incorporates the engineering involved in defining a product with the engineering required for its production.[15] This curricular concept is seen as completely consistent with the defined knowledge stems and the admonitions of the accreditation program criteria for 'manufacturing engineering'.[1,2,7,8]

materials & manufacturing processes
process, assembly & product engineering
manufacturing competitiveness
manufacturing systems design

Figure 5: Proficiencies Required in Accreditation Program Criteria for Manufacturing Engineering and Similarly-Named Programs [6]

At the same time, the opening years of the new century included an explosion of new manufacturing technologies, ushering in a sea change in the central products of importance to society and in the technologies for their manufacture …
… electronics manufacturing in a wide spectrum of size and scale applications;
bio-medical tools and instruments and prostheses;
production of energy;
the enormous product prospects enabled by micro- and nano-technologies.
For the manufacturing education community, this rush of new technologies exacerbated the continuing struggle with the familiar problems of incorporating new technologies in an already-overloaded curriculum, while still maintaining adequate treatment of fundamentals -- and within a relatively new influx of administrative and political pressures on curricular content. For veterans, this new rush evoked memories of the flood of computer-aided techniques that engulfed the discipline twenty years earlier.

A key response to the appearance of new manufacturing technologies and applications was a series of three by-invitation forums, sponsored by SME and focused on the issues of incorporating new technologies into twenty-first century curricula in manufacturing engineering.[1] These events had two focal points: an illumination of the nature and extent of the wave of new technologies for value-adding materials modification and an attempt to incorporate the emerging manufacturing technologies into contemporary curricula.

Responses to the challenges of the most recent decade have generated some promising initiatives: a high-level task force within SME to re-examine the role of education in the profession of manufacturing engineering; forums that [a] articulated technologies new to the generally-accepted field of 'manufacturing' and [b] broadened the focus in the discipline from 'production' to 'product realization'.[16,17,18] In parallel, a nascent movement to rename the university field of study to include 'product engineering' remains localized.[13,14,15] The lasting effect of these forums and parallel initiatives is yet to be determined.

2010+: Where does all of this rich history leave us? What progress has been made for manufacturing engineering education over the past quarter-century? What lessons have been learned and insights developed for addressing the persistent problems of our educational genre?

[1] June 2008 at Robert Morris University; November 2008 at State University of New York at Farmingdale; June 2009 in Austin.

The Good News: There is a well-developed foundation for defining curriculum. The results of successive study and debate over nearly three decades are rather consistent, and it is clear that the fundamental corpus of manufacturing engineering/manufacturing engineering technology education is well-defined.[1,2,7]

The Bad News: The persistent challenges that have plagued manufacturing engineering education remain at least as pressing today as they were nearly thirty years ago. Enrollments, laboratories and industry connectivity remain as critical problems for manufacturing educators.

Whither Now: The fundamental issues of the past three decades that underlie the more visible problems remain as the matters of central importance today. What is "manufacturing engineering"? What is the inviolable persona of the professional organizations that bear this title? What are the mutual responsibilities and dependencies between education and industrial practice?

The first of these great questions has been answered in a time-tested fashion. The remaining challenges are in implementation. The responsiveness of the ASEE Manufacturing Division and of the Society of Manufacturing Engineers, and of the newer players such as the Manufacturing Education Resource Center and other like-minded groups, is the most critical issue yet to be determined. Can these vitally-concerned constituencies mobilize effective initiatives? Will the industries that rely upon manufacturing engineering recognize the criticality of an effective and vibrant supply of new talent? Will this group recognize their measure of responsibility in assuring continuance of high-caliber new talent?

As the manufacturing education community once again attempts to frame a strategy to address the persistent problems, it would seem that the classic Einsteinian observation is very apt -- to repeat the same actions and expect a different result is a form of insanity. Since we observe the continuing centrality of the three major problems, it would seem compelling that drastically different approaches are needed.

A start has been made. The foundations of the part quarter-century are solid and clear, and there is a plethora of detailed guidance in the archives of the Manufacturing Division and of SME. The three forums of the past two years have focused attention on both the shifting nature of the technologies of manufacturing and some of the pathways towards solution of the persistent challenges that have been our lot throughout the history of the ASEE Manufacturing Division. The unique celebration of the silver anniversary of this Division being presented at this conference provides a focal point around which we might regain a confident and visible pride in our discipline as something unique and special.

Perhaps these are harbingers of re-vitalization … a renewed organizational encouragement of individual initiative … a school-by-school embrace of a reformed curriculum, with a product-centric emphasis and an exuberant embrace of new technologies … a dynamic voice in the telling of the story of manufacturing as a socially-vital, viscerally-exciting and personally-fulfilling career path.

The faithful in the community of manufacturing educators hope that this effort proliferates in energy and in effectiveness. It is to be hoped that enlightened industry partners will join the parade. Places where manufacturing educators come together are the primary organizations where the energy for this quest can be marshaled. The symbiosis forged between the ASEE Manufacturing Division and the Society of Manufacturing Engineers is crucial. Newer organizations also have a vital role to play and are to be much encouraged.

The key factor, however, is not organizational. It is personal. The response to the challenges for manufacturing education and manufacturing engineering, both old and new, in the post-2010 era depends on the vision, energy and commitment of individual people -- purposeful and self-directed, acting individually to a common purpose. It has always been thus.

A Call to Action: If there is a lasting solution to the continuing mix of dilemma that face manufacturing education, each of the three sets of players must contribute in their own ways. The organizations claiming to represent manufacturing education have a distinct role to play:

- -- vigorous and wide-spread professional and public communication of the message that socio-economic prosperity requires a vibrant manufacturing sector;
- -- elevation of the image of manufacturing from the century-old dirty-face commonly perceived in public and governmental circles to the modern reality of sophistication;
- -- leadership and persistence in reminding manufacturing companies and industries of their strategic stake in the vitality of university-level manufacturing education;
- -- leadership and sponsorship of effective means of communicating new technologies and pedagogical methods among and between manufacturing educators;
- -- effective advocacy of the manufacturing engineering profession in accreditation and licensing arenas.

Individual manufacturing companies and industry organizations also have a critically important role:

- -- investment of professional time and tangible resources to support learning on campuses that develop and maintain programs that are manufacturing-centric;
- -- investment in summer internships for faculty in manufacturing engineering and manufacturing engineering technology;
- -- recruitment and hiring of new graduates from accredited manufacturing engineering and engineering technology programs.

At the core of the future for manufacturing education lies the initiative and energy on individual campuses. Colleges, department and program leaders, while important factors in the equation, are not the source of sustainable reform. Individual faculty must provide the reality for a new face of manufacturing education.

- -- If you are concerned about the public image of manufacturing, live your life (both professional and personal) in the image you prefer.
- -- Be a participant in the socio-economic fabric of your community. Be seen as vitally concerned with your favorite industries and with your broader and general community.
- -- Sustain an active personal learning in new manufacturing technologies -- read, attend seminars, visit companies and laboratories.

-- Be aggressive and imaginative in curricular innovation. Decide from your own personal growth what new technologies to introduce into your courses and curriculum. Create new program titles and course names to convey the sense of excitement ion your corner of the campus. Invent your own ways to invigorate your courses and your program.
-- Communicate. To all of your constituencies -- prospective students and their parents, secondary schools, individual companies and industry groups, community leaders, and peers.

Perhaps, just perhaps, a combination of these actions will revitalize university-level manufacturing education -- and with it the influx of bright and able new manufacturing engineers into the economy. The absolutely vital core to any such transformation is the concerned individual. Do not wait for someone to point the way and tell you how. As the commercial slogan goes, "just do it".

Bibliography:

1. David Wells, Laura M. Caldwell and A. Allen Arthur; Technical Education for Advanced Manufacturing; Manufacturing Engineering Education Foundation, Society of Manufacturing Engineers; June 1986
2. Ideal Models in Manufacturing Education: Proceedings of the Curricula 2000 Workshop; A. Allen Arthur, David Wells and Paul J. Demers, editors; Society of Manufacturing Engineers; February 1990
3. International Perspectives on Manufacturing Education; David L. Wells, A. Allen Arthur and Michael Cunningham, editors; Society of Manufacturing Engineers; 1988
4. Detlef K. Koska and Joseph D. Romano; Countdown to the Future: The Manufacturing Engineer in the 21st Century; Society of Manufacturing Engineers; 1988
5. "Program Criteria for Manufacturing and Similarly Named Engineering Technology Programs"; 2007 Accreditation Yearbook; ABET, Inc.; 2008
6. "Program Criteria for Manufacturing and Similarly Named Engineering Programs"; 2007 Accreditation Yearbook; ABET, Inc.; 2008
7. Manufacturing Education for the 21st Century; Volume I, Curricula 2002 Report; Society of Manufacturing Engineers; 1995
8. Manufacturing Education for the 21st Century; Volume II, Compendium of International Models for Manufacturing Education; Society of Manufacturing Engineers; 1995
9. Manufacturing Education for the 21st Century; Volume III, Preparing World Class Manufacturing Professionals; Society of Manufacturing Engineers; 1996
10. Manufacturing Education for the 21st Century; Volume IV, Manufacturing Education Plan, Phase I Report; Society of Manufacturing Engineers; 1997
11. Manufacturing Education for the 21st Century; Volume V, Manufacturing Education for Excellence in the Global Economy; Society of Manufacturing Engineers; 1998
12. David L. Wells; "SME and Accreditation"; White Paper; Society of Manufacturing Engineers; September 2007
13. Beverly J. Davis and Hugh Jack; "Reinventing Manufacturing Engineering: Refocusing and Exploring Future Opportunities for Students"; *Annual Conference*, American Society for Engineering Education; Portland; June 2005
14. Hugh Jack; "A Reborn Product Design and Manufacturing Program"; *Annual Conference*, American Society for Engineering Education; Portland; June 2005
15. "Engineering – Product Design and Manufacturing"; Grand Valley State University, www.gvsu.edu; accessed January 2010
16. David L. Wells; "A Framework for Student Learning in Manufacturing Engineering": *Annual Conference*, American Society for Engineering Education; Chicago; June 2006
17. David L. Wells; "Revisiting Core Competencies of Manufacturing Engineering in an Era of Technological Revolution"; *Manufacturing Education Transformation Summit*, Society of Manufacturing Engineers; Austin, June 2009

18. David L. Wells; “Incorporating Advanced Manufacturing Technologies into Undergraduate Education”; *Annual Conference*, American Society for Engineering Education; Austin, June 2010