ACS Sustainable Chemistry & Engineering

Feature

pubs.acs.org/journal/ascecg

Building a Sustainability Road Map for Engineering Education

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ABSTRACT: Major environmental, economic, and social trends are transforming the application of sustainability thinking within the engineering profession and within organizations that hire engineers. These include the growing demand for new kinds of knowledge, skills, and abilities to respond to global megatrends; an increased awareness and understanding of sustainability challenges among engineering students; the application of quantitative engineering skills for business risk management; and further developing the entrepreneurship curricula to transform inventions into marketplace innovations and societal solutions. This feature article addresses the need for a sustainability roadmap in engineering curricula; identifies the major elements of such a framework; reviews collaboration strategies for engineering schools, the public sector, private companies, and non-governmental organizations; and presents specific recommendations for curricula development and expanding the influence of engineering professionals in developing solutions to growing societal challenges.

KEYWORDS: *Sustainability, Megatrends, Action-based learning, Systems thinking, Innovation, Collaboration, Solutions*

The multi-disciplinary nature of sustainability creates a variety of challenges in applying different kinds of knowledge that can inform engineering decisions. Engineers are well versed in the mass and energy balances that form the foundation of thinking about sustainability. Many practicing engineers and engineering faculty began their careers before sustainability became a widespread concept in business and other professions, thus providing a perspective that sustainability is a more abstract concept rather than a quantifiable science. Great debate continues to evolve concerning the definition of sustainability, the scope and scale of its application to engineering challenges, and its future evolution.[1] We believe that engineers must help to shape this discussion because it is engineers that will ultimately develop and deploy many of the solutions that address sustainability challenges.

Several major environmental, economic, and social trends are transforming the application of sustainability thinking within the engineering profession. They include (1) the growing demand within the private sector and other employers for sustainability-related knowledge, skills, and abilities to respond to major global trends such as the expanding middle class in developing nations, intensified patterns of urbanization in non-western nations, challenges in providing sufficient quantities of food and water supplies, and accelerating climate change; (2) an increasing awareness and understanding of sustainability challenges among engineering students coupled with their greater advocacy for sustainability content in their course work that includes case studies, best practices, and access to a broader community of sustainability professionals in engineering and other disciplines; and (3) an emerging core body of knowledge that integrates business fundamentals with sustainability principles and metrics that is being developed by universities, engineering societies, the private sector, and non-governmental organizations. The result of these developments is that the concept and application of sustainability has become more specific and increasingly accepted by a widening range of institutions and professions.

In reflecting upon the development of a sustainability roadmap, or framework, for engineering education, four foundational questions should be addressed. (1) Why is there a need for such a roadmap? (2) What are the major elements of a roadmap? (3) What constitutes the core sustainability body of knowledge and practices? (4) How can engineering schools work more collaboratively within their own universities and across other institutions to accelerate learning?

Received: August 22, 2013
Revised: October 22, 2013
Published: November 13, 2013

THE CASE FOR A ROAD MAP

Introducing new concepts and material into the current engineering curricula, already jam-packed with courses, modules, guest lectures, and case studies, is a challenge. Engineering departments must integrate sustainability thinking into the curricula because engineers are increasingly being asked to address these issues in their workplaces. Even though sustainability courses (or elements in courses) are increasingly becoming part of the curriculum, what is missing is cross-disciplinary content. In addition, newer multi-disciplinary boundaries have evolved in what now constitutes relevant engineering theory, concepts, and content. For example, there are universal methods by which engineers can design buildings or other infrastructure for transportation or water supply, and the results of these methods are measurable and predictable in their outcomes. However, if the choices presented to engineers are expanded to include the life cycle impacts of materials chosen for a project, the need to integrate "smart technologies" and "greener solutions" into infrastructure design, and the task of evaluating secondary or tertiary impacts upon communities or the availability of natural resources, the engineering boundary conditions have dramatically shifted. Emerging evidence from the marketplace and other global trends suggest that these and similar questions are being posed with ever increasing frequencies.

Second, the needs of organizations that hire engineers are changing. Fundamentally, hiring organizations in the private sector, consultancies, and government are increasingly becoming proponents of "action-based learning", the idea that students and professors should gain more direct experience by working in factories, across value chains, or in policy relevant positions. These experiences are necessary to the acquisition of new skills and abilities that include systems thinking; life cycle assessment; data analysis and interpretation that includes the social context of design and decision making; managing uncertainty across time and space; adapting to unanticipated consequences; acquisition of personal skills through working in teams of colleagues across diverse genders, languages, geographies, and cultures; ability to communicate work plans or a policy proposal with external stakeholders; participation in new models of innovation and governance; and understanding of business fundamentals and value creation in the enterprise. For engineers to continue to implement their historic mission of driving the advance of civilization, there is a growing need to respond to these and other challenges that are emerging from an expanding set of societies' needs.[2]

Third, students themselves are changing and represent an important impetus for a modified engineering curricula. Many contemporary students now come to their educational institutions with an understanding that they will live in a world of resource limitations and social inequities. In addition to formal classroom instruction, they are participating in networks and other non-course learning and are thinking conceptually of how to improve conditions in the world through better use of limited resources. They also increasingly "vote with their feet" and are choosing business and public policy courses to supplement their engineering core. Students' demographic profile and countries of origin have dramatically changed in recent decades, and their sophistication greatly exceeds that of preceding generations of students due to their access to information technology, travel, and other life experiences.

Taken together, these factors have acquired considerable momentum across a growing number of university campuses. Appropriately designed and executed, the integration of sustainability into engineering curricula can create the opportunity for major new innovations and an expanded role for engineers to address the problems of society both now and in the future.[3]

A central point is that the integration of sustainability concepts and knowledge into the engineering curricula is additive to the principles and technical soundness of current teaching methods. The sustainability roadmap, or framework, for engineering education by necessity must build on technically sound teaching foundations already established and are not a substitute for them.

ELEMENTS OF THE SUSTAINABILITY ROAD MAP AND CORE BODY OF KNOWLEDGE

As noted by Allen and Shonnard, there are three levels to organizing knowledge to integrate sustainability into the engineering curricula.[1] To this framework can be inserted a core body of content for teaching current and future generations of engineering students. Relevant content includes the following.

Framing the Sustainability Challenge: Information relevant to this knowledge level would include a survey of government laws and regulations relevant to sustainability; corporate sustainability reports that document business strategies, policies and other commitments; review of global megatrends that document population growth, urbanization, natural resource consumption patterns, and scarcities; pollution loadings; analyses of economic value chains and their demands for and impacts on materials, natural systems, and people; and risk and life cycle frameworks for assessing both specific issues and broader trends.

Assessment and Design: Consideration of sustainability issues is compatible with established methods of teaching the various engineering disciplines but also extends the boundaries of those methods. For example, metrics that incorporate sustainability thinking would proceed from measures of molecular and process factors to also include a product and system level scope. Other aspects include information on not only the principles of designing for sustainability but also the objectives (e.g., rethinking the design parameters of a new auto manufacturing plant to not only optimize the efficiency of water use but to achieve net zero consumption of water), development and use of newer tools and case studies, evaluating the secondary and tertiary impacts of a range of engineering design choices, and quantifying sustainability impacts.

Systems Thinking: Engineers have made noteworthy contributions to human progress because of their training as problem solvers. Today's decision makers face a growing array of problems that are interlinked and that exist on local, regional, and global scales simultaneously. For example, future decisions on the next generation of passenger vehicles will need to take into account not only the materials for designing and building the vehicle but also the increasing reliance on "smart" technologies that enable individual vehicles to communicate with each other to optimize traffic flow at various times of the day, demands for power generation to provide electricity for individual and networked vehicles, the expansion of consumer mobility, and the potential restrictions on the number of vehicles permitted in congested urban areas. Only a "system-level" perspective on the characteristics and goals across these functionalities will enable engineers, and those that rely upon their expertise, to develop more innovative solutions to both engineering and societal challenges. This will necessitate a process of rethinking and updating material flow analyses, case studies, and other tools needed by engineers.

■ ACCELERATING LEARNING THROUGH COLLABORATION AND NON-TRADITIONAL MODELS

Corporations, government agencies, non-governmental organizations, and universities are increasingly recognizing that they will be more successful in attaining their individual objectives by collaborating with other partners with aligned interests, knowledge, and institutional capacities that supplement their own. For more than a decade, there has been an accelerated commitment to the formation of such "corporate responsibility coalitions" to address such issues as climate change, access to potable water supplies, HIV/AIDS and tropical diseases, and habitat protection.[4]

More specifically, innovations in institutional collaboration have emerged among global companies, non-governmental organizations, and the public sector to generate new scientific and engineering knowledge. The Nature Conservancy, one of the largest conservation organizations, and The Dow Chemical Company, one of the world's pre-eminent chemical manufacturers, have developed a strategic partnership to document and demonstrate the value of ecosystems and the services they generate. The partnership includes new means of integrating both man-made and natural infrastructures for such applications as air pollution mitigation through reforestation, biodiversity protection, flood prevention, coastal hazard mitigation, stormwater protection, wastewater treatment, and water flow regulation. CH2M HILL, a global engineering consultancy, has partnered with the U.S. Department of Defense (through its Environmental Security Technology Certification Program, or ESTCP) to develop Net Zero Energy, Net Zero Water, and Net Zero Waste performance goals to create new engineering solutions for the next generation of installation capital investments. Royal Dutch Shell has also brought together leading business and other organizations to shape collaborations across value chains in order to address more "resilient solutions". In other examples, new engineering designs and assessments have emerged that lead to expanded decision making options and calculations of costs and benefits to business and the public. These and other knowledge generating partnerships have emerged without the participation of universities.

Engineering schools must include sustainability in the curricula by adopting initiatives that are both internal and external to the university. Recommended options include the following. (1) Lowering barriers across disciplines. Technical knowledge within individual disciplines is valuable, but it must be integrated with concepts and methods developed by other peers if today and tomorrow's engineering students hope to advance their career opportunities. (2) Expanding the participation of faculty and students in learning opportunities outside the classroom. This can take many forms, including student internships within companies or actual projects within factories or involvement in other business functions (e.g., supply chain management, logistics). (3) Moving from one-off engagement with business on individual projects to more strategic relationships that advance both insights and value. As one example, the University of Michigan has mobilized its alumni network with social media to identify faculty and student opportunities to work with companies that employ Michigan graduates.

The private sector can also enhance its value as a collaboration partner with engineering schools through a variety of actions. They include the following. (1) Adopting a longer-term planning horizon (at least 10 years) for investing in knowledge generation. This will be especially important given that the system-level challenges facing modern society will take many years to resolve. (2) Providing opportunities for senior executives to participate with faculty and students as part of curricula design and accelerating the development of and access to case studies so that what is taught in the classroom reflects current business thinking and practices. (3) Building a strategy for engaging with engineering schools. Companies such as CH2M HILL, Dow Chemical, ExxonMobil, and Royal Dutch Shell have developed longer-term partnerships for staying abreast of developments in the various engineering disciplines and acquiring the talent they will need in future years. (4) Partnering with other institutions, such as the National Science Foundation, that foster collaborative approaches for developing innovative, sustainability-related, educational content.

■ NEXT STEPS

Building a sustainability roadmap for engineering education will require a major commitment from engineering schools, global companies, government agencies, and non-governmental organizations to establish new mechanisms for collaboration. The first objective of such collaboration should be to identify and develop the content necessary to meet existing standards for educational excellence, achieve relevance to current engineering curricula, and prepare engineering students to implement sustainability in the future. Fortunately, much of this content is already available—and growing—and it is increasing in both quality and accessibility.

Implementing the sustainability roadmap cannot be a one-size fits all proposition for engineering schools. Common principles are desirable, but the integration of sustainability into the core engineering curricula should be flexibly implemented by individual universities so as to be compatible with their core competencies. Sustainability is merely the application of sound engineering principles and values to address environmental and societal challenges. Many of the tools to implement sustainability thinking already exist within the engineering disciplines or are easily accessible.

Engineering schools represent a critical resource of knowledge creation and dissemination and talent development for solving today's increasing global challenges. These challenges, far from being abstract or in the future, have greatly accelerated in both time and scale. The task of integrating sustainability concepts and practices within engineering curricula is urgently needed. While engineering schools have begun to integrate sustainability in courses and programs, it is now time for engineering disciplines to exhibit more aggressive leadership by bringing sustainability principles and practices into the core of what students are taught.

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Notes

The authors declare no competing financial interest.

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