Status and Prospects of Sustainable Engineering Education in Some American Universities

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1. Introduction

The concept of sustainable development has only begun to influence the world of engineering education. Decades of effort will be needed to embed the concept in every aspect of study. During this long transition, advocates of the new paradigm must maintain a realistic perspective on the extent to which sustainability is truly incorporated into engineering education, and must seek to understand the factors that promote or retard this incorporation.

This paper contributes to the development of a realistic perspective, by briefly reviewing the status and prospects of sustainable engineering education in a small sample of American universities, each of which is located in the vicinity of Boston, Massachusetts. These are: Boston University; Massachusetts Institute of Technology (MIT); and Tufts University. Such a limited review cannot, of course, provide a definitive picture of sustainable engineering education in the United States. Instead, the purpose of this paper is to contribute to the development of generally-accepted criteria and methodologies that will, ultimately, be used to assess sustainable engineering programmes at universities in the United States and elsewhere.

To provide a context, the paper begins by discussing the positions that have been set forth by some relevant American institutions, regarding sustainable development and its significance for engineering education. Then, the paper reviews the criteria for engineering education programmes that have been set forth by the Accreditation Board for Engineering and Technology (ABET). Drawing from this material, the paper then articulates some expectations for the role of sustainability in engineering education. These expectations provide a framework for our review of engineering education programmes at the three selected universities. That review focuses on undergraduate engineering programmes that are accredited by ABET.

2. Positions of some relevant American institutions regarding sustainability

Many institutions, in the United States and elsewhere, have articulated positions about sustainable development and its significance for education. Here, we discuss positions that have been set forth by two institutions that are especially relevant to engineering education in the United States.

A committee of the US National Science Foundation (NSF) has recently published, in draft form, a 10-year agenda for environmental research and education at NSF. In its final form, this agenda will provide direction for the environmental research and education programmes of NSF over the period 2003-2012. NSF is a US government agency that is a major provider of funding for science-related research and education. The Introduction to the draft agenda begins with the statement (National Science Foundation Advisory Committee on Environmental Research and Education, June 2002):

> "The most challenging scientific and engineering problems we face at the beginning of the 21st century are environmental, including rapid climate and ecological change, the degradation of freshwater resources, the globalization of disease, the threat of biological warfare and terrorism, and the more complicated question of long-term environmental security. The footprint of human activity continues to expand, to the point that it has a significant impact on nearly all of the environmental systems on the planet. Increasingly, we are becoming the designers and managers of the complex relationships among people, ecosystems and the biosphere. Human and environmental health are often highly intertwined, and human well-being is inextricably linked to the integrity of local, regional and global ecosystems. Environmental research and education are therefore key elements of local, national and global security, health and prosperity."

These general principles were recognised almost a decade ago by the American Association of Engineering Societies (AAES), whose member organizations represent more than 800,000 persons active in engineering design, construction, management, research and education in the United States. In 1994 the AAES set forth a statement on "The Role of the Engineer in Sustainable Development". That statement contained a section, titled "Sustainable Development Education for the Profession and the Public", which reads as follows (American Association of Engineering Societies and the World Engineering Partnership for Sustainable Development, 1994, page 5):

> "As facilitators of sustainable development, engineers must acquire the skills, knowledge, and information which are the stepping stones to a sustainable future. The promotion of sustainable development demands that engineers cultivate an understanding of the environmental issues, problems, and, especially, risks and potential impacts of everything we do. Engineering education must instill in its students an early respect and ethical awareness for sustainable development, including an understanding and appreciation of cultural and social characteristics and differences among various world communities. In addition, we must provide

our students with the analytical tools to assess risks and impacts, to perform life cycle analysis, and the ability to solve technical problems, cognizant of and taking into consideration the economic, socio-political and environmental implications. Moreover, we must strive to educate all elements of society and promote universal adoption of a sustainable development ethic; particularly among private and public sector decision makers, developers, investors, and local, regional, national, and international governing bodies."

3. Accreditation of engineering education programmes by ABET

This paper focusses on undergraduate engineering programmes that are accredited by ABET or, to be more specific, by ABET's Engineering Accreditation Commission. Each of our three selected universities has several engineering programmes of this kind. ABET accredits programmes only within the United States, but has mutual recognition agreements with accrediting organisations in some other countries. In order to be accredited by ABET, an engineering programme must meet a set of general criteria and a set of criteria that apply to the particular engineering specialty that the programme addresses (Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology, November 2001).

The general criteria contain several provisions that are relevant to sustainable development. Criterion 3, which addresses Program Outcomes and Assessment, states that an engineering programme must demonstrate that its graduates have acquired skills and knowledge in 11 categories. Of these categories, two are especially relevant to sustainability. Category (f) requires "an understanding of professional and ethical responsibility" and Category (h) requires "the broad education necessary to understand the impact of engineering solutions in a global and societal context". Criterion 4, which addresses the Professional Component of engineering education, includes the following statement:

> "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political."

4. Expectations for the role of sustainability in engineering education

In light of the positions set forth by NSF and AAES, and the accreditation criteria articulated by ABET, it is reasonable to expect that any undergraduate engineering programme in the United States will assign a significant priority to issues of sustainability. There is considerable room for debate and experiment about incorporating sustainability into an engineering curriculum, but four points seem clear.

First, much of the curriculum should not require alteration. Engineering for sustainability requires the same basic mathematical and scientific competence as engineering for any other purpose. Indeed, an education that stresses scientific rigour and encourages scientific curiosity can help a student to understand the imperatives of sustainability, and to accommodate the additional factors that must be considered in engineering for sustainability. Also, the general skills -- such as communication, life-long learning and functioning in multi-disciplinary teams -- that are now imparted by good engineering programmes will be equally necessary in a curriculum that addresses sustainability.

Second, every engineering graduate should have a basic knowledge of the biosphere and human impacts on the biosphere. Thus, for example, every engineering graduate should be familiar with the hydrologic, carbon and nitrogen cycles of the Earth, and with human perturbations of these cycles. The graduate's depth of knowledge should be sufficient to allow effective communication with specialists in biospheric processes.

Third, every engineering graduate should have a basic knowledge of the ways in which human-caused impacts on the biosphere -- including impacts on present and future humans -- are affected by forms of social organisation, patterns of human activity, and technological choices. Thus, for example, every engineering graduate should be familiar with large-scale demographic trends, and with the environmental footprints of past and present societies. Again, the graduate's depth of knowledge should be sufficient to allow effective communication with specialists.

Fourth, every engineering graduate should have a major design experience that accounts for a range of realistic constraints, including sustainability. ABET has already specified this requirement.

5. Engineering education at Boston University

Boston University's College of Engineering offers ABET-accredited programmes that award Bachelor of Science degrees in aerospace, biomedical, computer systems, electrical, manufacturing or mechanical engineering. The College also offers a degree in interdisciplinary engineering, but this programme is not accredited by ABET. This paper draws its information about the various engineering programmes from the Boston University Undergraduate Bulletin 2001/2002 (Boston University, July 2002).

All engineering undergraduates are required to have a common academic experience (the lower division requirements), much of which occurs during the first two years of the four-year programme of studies. The components of this common experience are: mathematics; natural sciences; a writing requirement; social sciences; humanities; and the engineering core requirements. The natural sciences requirement for biomedical engineering students includes biology, physics and chemistry, but other engineering students are required to study only physics and chemistry. A variety of courses are acceptable for the purpose of meeting the social sciences requirement. Of the acceptable social science courses, one course -- CAS GG 100, Introduction to Environmental Science -- relates directly to sustainability. One of the courses available to meet the engineering core requirements -- namely ENG EK 280, Technology and Society -- relates to sustainability.

Building upon the common experience provided by the lower division requirements, an engineering undergraduate must also meet a set of upper division requirements that are specific to the specialist degree that the student is seeking. Numerous courses are available to meet the upper division requirements. Of these courses, three design courses offered by the aerospace and mechanical engineering department relate to sustainability, in the sense that they address engineering ethics. These courses are: ENG AM 312, Fundamentals of Engineering Design; ENG AM 413, Machine Design I; and ENG AM 414, Machine Design II. One course offered by the electrical and computer engineering department -- namely, ENG SC 566, The Atmosphere and Space Environment -- relates to sustainability.

A search of the Boston University Undergraduate Bulletin reveals two courses whose primary focus is sustainability. One is an international relations course, CAS IR 304, Environmentally Sustainable Development. The second course -- CAS EE 304, Environmentally Sustainable Development -- is offered by the Center for Energy and Environmental Studies. Several other courses offered by this Center also relate to sustainability. It appears, however, that engineering undergraduates in ABET-accredited programmes are not likely to take any of these courses.

To summarise, Boston University offers a traditional engineering curriculum, with limited exposure to sustainability issues.

6. Engineering education at MIT

MIT's School of Engineering offers several ABET-accredited programmes that award Bachelor of Science degrees. This paper draws its information about these programmes, and related programmes at MIT, primarily from the MIT Bulletin 2001-2002 (MIT, July 2002). Some information is drawn from other documents available via the MIT website. The ABET-accredited undergraduate engineering programmes are as follows:

• aeronautics and astronautics (with two variants, focussed on aerospace vehicles, and aerospace information technology, respectively)
• chemical engineering
• civil and environmental engineering (with two variants, focussed on civil engineering, and environmental engineering science, respectively)
• electrical engineering and computer science (with three variants, focussed on electrical science and engineering, electrical engineering and computer science, and computer science and engineering, respectively)
• materials science and engineering
• mechanical engineering
• nuclear engineering (with two variants, focussed on nuclear energy, and radiation for medicine and industry, respectively)
• ocean engineering

All MIT undergraduates must meet the General Institute Requirements (GIRs) for a Bachelor of Science Degree. Students take GIR-related courses throughout the four years of their programme of studies, but they typically focus more heavily on these courses in the first year. The GIRs account for roughly half the number of courses and half the number of credit units in an undergraduate student's programme.

The GIRs include courses in mathematics, chemistry, physics and biology. They also include laboratory, physical education and communication requirements. Another GIR requirement is that the student must take two courses from a list of restricted electives in science and technology (REST). Several of the REST courses relate directly to sustainability, but many do not. Finally, the GIRs include a humanities, arts, and social sciences (HASS) requirement. The student must take eight HASS courses, including two communication courses and three courses from a list of "HASS-Distribution" courses; this list contains a wide variety of courses, of which a few relate to sustainability.

In addition to meeting the GIR requirements, an undergraduate engineering student must meet a set of requirements that are specific to the specialist degree that the student is seeking. For each such degree, the relevant engineering department specifies required courses and restricted electives (i.e., courses chosen from a limited list). Students are also allowed to take a number of unrestricted elective courses, consistent with obtaining the number of credit units needed to graduate. As would be expected for a university of the size and complexity of MIT, the array of courses that students may take within the various undergraduate engineering programmes is too large and varied to summarise in this paper.

MIT is a member of the Alliance for Global Sustainability, which brings together research teams from four research universities: the Swiss Federal Institute of Technology Zurich-ETH; the University of Tokyo; Chalmers University of Technology; and MIT. Also, MIT operates the Laboratory for Energy and the Environment (LFEE), which has made the following statement about its educational mission: "All students at MIT need to understand what is happening in the world that we inhabit, to be aware of how human activities are influencing this world, and to acquire a sense of responsibility for the Planet and its inhabitants."

Given this level of attention to sustainability, one expects MIT to offer a range of courses that relate to sustainability. The LFEE has identified and listed courses of this kind, under the rubric "environmental classes". A review of this list shows many courses, offered within and outside the School of Engineering, that relate, in varying ways and to varying degrees, to sustainability. Further investigation is needed to determine the extent to which these courses, and the taking of such courses by engineering undergraduates, meet the expectations set forth in Section 4, above.

Pending the completion of further investigation, our initial review of MIT's undergraduate engineering programmes allows some interim conclusions. First, some programmes -- especially the programme in environmental engineering science -- give significant attention to sustainability issues. Second, the required courses in other programmes give limited attention to sustainability. Third, motivated students can take restricted or unrestricted elective courses that compensate, to some extent, for the limited treatment of sustainability within a specialist programme. Overall, the picture is one in which engineering students vary widely in their exposure to sustainability issues, but there is promise of increasing the exposure of under-served students in the future.

7. Engineering education at Tufts University

Tufts University's School of Engineering offers ABET-accredited programmes that award Bachelor of Science degrees in chemical, civil, environmental, electrical, computer and mechanical engineering. This paper draws its information about these programmes primarily from Tufts University's Bulletin for Arts, Sciences, and Engineering (Tufts University, July 2002).

Each ABET-accredited engineering programme requires that a student obtains 38 credit units before graduation. Eleven of these credits must be obtained from a common program of introductory courses in mathematics, physics, chemistry, engineering, engineering electives, natural science electives (in physics, chemistry, biology, or geology), and English. Eight credits must be obtained from "foundation" courses selected from a list approved by the department in which the student is seeking a degree; these courses address biology, chemistry, computer science, engineering science, geology, mathematics, physics and astronomy. Twelve credits must be obtained from "concentration" courses that are required for a particular degree. Five credits must be obtained from humanities, arts and social science courses that are selected from an approved list; of these approved courses, only one -- in urban and environmental policy -- relates to sustainability. Finally, two credits must be obtained from unrestricted elective courses.

As a result of this credit structure, students' exposure to sustainability issues will occur primarily through engineering courses and, for motivated students, through sustainability-related courses that are taken as unrestricted electives. Some of the available engineering courses, especially in environmental engineering, relate closely to sustainability. The Chemical and Biological Engineering department offers two courses -- Technological Processes and the Environment, and Clean Energy Technologies and Policy Issues -- that are notable for their relevance to sustainability. However, most of the available engineering courses do not address sustainability. Thus, many students could graduate with little exposure to sustainability issues.

Through the two-credit, unrestricted-elective requirement, motivated students could take courses that address sustainability issues. Relevant courses are available from, for example, the Urban and Environmental Policy department at Tufts.

Further investigation is needed to determine the extent to which the available courses that relate to sustainability, and the taking of such courses by engineering undergraduates, meet the expectations set forth in Section 4, above. Pending such investigation, it appears, as at MIT, that engineering students at Tufts vary widely in their exposure to sustainability issues. The opportunity for an under-served student to obtain such exposure may be somewhat less at Tufts than at MIT.

8. Conclusions

Leading institutions in the United States have recognised that sustainable development should have a prominent role in engineering education and practice. The criteria used to accredit engineering education programmes have also recognised this need. Thus, it is reasonable to expect that sustainability will be incorporated into the curriculum of any accredited, undergraduate engineering programme in the United States.

A limited, initial survey of engineering programmes at three American universities shows that many students are not receiving significant exposure to sustainability issues. Some programmes at some universities are providing significant exposure, but others are not. Further investigations are needed, to determine how well students are being served at present, and how they may be better served in the future. Criteria and methodologies developed through such investigations could, ultimately, be used to assess sustainable engineering programmes at universities in the United States and elsewhere.

9. References

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