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Editorial

Forty-nine shades of green: ecology and sustainability in the academic formation of engineers

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Abstract

'Ecological engineering' is relatively recent. It resembles chemical, hydrological and other engineering where the title indicates another discipline specialisation (ecology, chemistry, hydrology) is closely associated. Differently, civil, mechanical, or electrical engineering titles indicate engineering subdivisions based on areas of application. The ecological engineering title is twice asymmetric: it indicates a kind of engineering, not science (engineering ecology); and only part of ecological science has as yet been included in ecological engineering. The 'civil' engineering descriptor is defined by its context, rather than this area being defined by its descriptor. Civil engineering includes a specialisation with another inappropriately undescriptive title—environmental engineering. Ecological and environmental engineering are readily confused by the public, ecologists, and other engineers. There have recently been laudable efforts by engineers, ecologists, economists, writers, and many others to move society towards more sustainable living. Young engineers can be encouraged in this by greater understanding of ecology and sustainability in their academic and professional formation. The desirable formation of ecological engineers remains unclear. Meanwhile, many approaches exist to introducing ecological understanding and principles of sustainability into other engineering academic curricula. Some approaches are discussed in this paper, in the context of developing appropriate education and training in ecological engineering.

Keywords: Ecological engineering; Specialisations; Environmental engineering

1. Introduction

Ecological engineering is a relatively recent kind of engineering. Its origins lie not in engineering, but in systems ecology. Howard T. Odum stated in his 1971 book *Environment, Power and Society* (Odum, 1971, p. 274): 'The management of nature is ecological engineering, an endeavour with singular aspects supplementary to those of traditional engineering. A partnership with nature is a better phrase.'

Mitsch (1998) quotes earlier work by Odum and his colleagues describing ecological engineering as involving 'those cases in which the energy supplied by man is small relative to the natural sources, but sufficient to produce large effects in the resulting patterns and processes' (Odum, 1962). Noting the 'thousands of years' during which ecological en-

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gineering practice has been developing in China, Mitsch (1998) quotes another description of ecological engineering as '... a specially designed system of production processes in which the principles of the species symbiosis and the cycling and regeneration of substances in an ecological system are applied ...' (Ma et al., 1988).

In his review paper, Mitsch (1998) tabulates 18 'synonyms, subdisciplines, or fields similar to ecological engineering'. That is one every 2 years on average since Odum in 1962! In order to have a clear discussion on appropriate form and content of a curriculum for ecological engineering, as intended in this paper, some preliminary statements on semantics are desirable.

2. Semantics

A hierarchy is adopted in this paper for naming subdivisions of professional engineering. Engineering is considered to be a 'discipline', like science, or medicine. The main subdivisions of engineering, by historic use civil, mechanical, electrical, chemical are then 'sub-disciplines'. So might agricultural engineering and mining engineering, for example, be considered to be sub-disciplines.

But this becomes a moot point when aeronautical engineering and automotive engineering are considered, as here, to be 'specialisations' within mechanical engineering; structural engineering and geotechnical engineering are specialisations within civil engineering; electronic engineering and telecommunications engineering are specialisations within electrical engineering; and biochemical engineering and petroleum engineering are specialisations within chemical engineering. What then is railways engineering, with its mix of structures and machines? What is marine engineering? In the present context, where does ecological engineering fit in the hierarchy? Is it a new sub-discipline? Is it a specialisation of an existing sub-discipline, perhaps? In the light of its origins in ecology, is it even engineering?

A further semantic distinction is necessary to clarify subsequent discussion: between 'ecological' engineering and 'ecological engineering'. A similar distinction has previously been drawn (Elms, 1995) between 'environmentally-educated' engineers and 'environmental engineers'. It can be hoped that engineers from a variety of sub-disciplines and specialisations will ensure in future activities that they are aware of, and considerate towards, the ecosystems with which their projects interact. In short, that they take an 'ecological' engineering approach. This is different from the 'ecological engineering' considered here as a candidate specialisation or sub-discipline within engineering.

A final semantic point is that 'ecological engineering' and 'engineering ecology' are different, in the same way that hydrological engineering and engineering hydrology are different. The first of each pair are kinds of engineering, whereas the second of each pair are kinds of science. 'Ecological engineering' is a similar kind of title to chemical engineering, hydrological engineering or aeronautical engineering, in which there is recognition in the title that another sub-discipline (ecology, chemistry, hydrology, aerodynamics), usually of the science discipline, is closely associated. This is semantically different from such sub-discipline titles as civil engineering, mechanical engineering, or electrical engineering, which indicate subdivisions of the engineering discipline based on their areas of application.

3. Why develop 'ecological engineering'?

The enhanced public awareness of environmental degradation from the 1960s onward has affected engineering curricula. One obvious effect was the initiation of programs of 'environmental engineering' from about 1962 in the USA (ABET, 2002). Many of these grew out of the 'public health and sanitary engineering' specialisation of civil engineering. Environmental engineering focussed on waste clean-up and waste management in the built environment.

Another thread in the tapestry of responses to the 1960s enlightenment arose from the work of Howard Odum and his colleagues, referred to in the Introduction. Concentrating at first on energy flows in the environment (in contrast to material and financial flows), this thread included the idea that ecological engineering involved using small amounts of supplied energy to manipulate natural systems having their own major energy sources, such as solar and bioenergetic energy.

A recent, related concept is that of resource productivity (Hawken et al., 1999). Humankind has been preoccupied since the 18th–19th Century Industrial Revolution with increasing human productivity through built technology, at the cost of environmental degradation and profligate waste of natural resources. To ensure sustainability and ecosystem well-being, attention must now shift to obtaining more product from less resource, with less waste, and less damage to the environment. Already there are achievements of 'factor four' (von Weizsäcker et al., 1997), and even 'factor 10'.

One important answer to 'Why develop ecological engineering?' is that it is not focussed passively on waste clean-up and waste management in the built environment, but proactively on 'the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both' (Mitsch, 1996). It thus has the potential to provide resource productivity, including energy productivity in the Odum (1971) sense, while maintaining a focus on sustainable ecosystems. So far, 'ecological engineering' has been doing this in a relatively limited set of contexts, notably constructed wetlands, wastewater, and aquaculture, out of the total contexts which ecological science considers. And 'ecological' engineering, as discussed earlier, remains a hope rather than established professional activity in most engineering sub-disciplines (Painter and Dakers, 1997).

4. What is in ecological engineering?

There is considerable consensus, at least in the eight countries which recognise each other's professional engineering qualifications through the 'Washington Accord' (Australia, Canada, Hong Kong, Ireland, New Zealand, South Africa, UK, USA; see IPENZ (2002)), about the general content of undergraduate engineering degree programs. A grounding in mathematics, computation, physics, chemistry, mechanics and design is usually common to all sub-disciplines. Then the engineering science built on these becomes more specific to the sub-discipline, while the applied mathematics and design are taken to higher levels. Content related to communication skills, financial and people management, and other professional practice, often becomes more prominent towards the end of the program.

More recently, in particular following the UN Conference on Environment and Development at Rio de Janeiro in 1992 (UN, 1992), engineering undergraduate programs in some countries have made it mandatory to include 'awareness' of sustainability and the concept of sustainable development in the undergraduate curriculum (e.g. IPENZ, 2000; IEAust., 1999). The 2000–2001 Strategic Plan of the World Federation of Engineering Organisations (WFEO, 1999) includes 'education for sustainable engineering' among its long-term goals.

So what should be in a curriculum for ecological engineering? It was argued earlier that 'ecological engineering' is a kind of engineering (not science), and is different from 'ecological' engineering (in other engineering sub-disciplines and specialisations). Therefore the foundation of mathematics, computation, physics, chemistry, mechanics and design common to all engineering sub-disciplines should be included in the ecological engineering curriculum. But biology should be added, and should lead on in the engineering science to an understanding of ecological systems and some of the tools of applied ecology. Later design should include system self-design (Odum, 1971). The sustainability ethos should pervade the whole program, exceeding the requirements currently being mandated by some accrediting authorities, because these apply to 'ecological' engineering—not 'ecological engineering'.

The end-of-program applied engineering and professional courses should vary according to regional and country requirements. It would be appropriate if these were to concentrate at first on the applications (such as wetlands, wastewater and aquaculture) that are already associated with organisations such as the International Ecological Engineering Society (IEES, 2002) and the American Ecological Engineering Society (AEES, 2002). Development should occur to give graduates the skills and understanding, to provide the engineering needed, to complement the scientific knowledge in those fields of ecology that are not currently well-served by existing sub-disciplines and specialisations of engineering. Graduates need employment; which new fields are to influence curricula will depend on the employment opportunities to which they relate. In New Zealand, for example, they might include the ecological science associated with conservation forestry and eco-tourism.

5. How to include ecology and sustainability

How the specifically 'ecological' and 'sustainability' aspects of a curriculum should be included in an ecological engineering program depends on their nature. The fundamentals of biology can be imparted alongside those of physics, chemistry and mechanics, using learning methods appropriate to all. So too could understanding of ecological systems, familiarity with some of the tools of applied ecology, and concepts of self-design be included using familiar learning methods.

Although sustainable development and sustainable management can be introduced as part of conventional learning in appropriate courses, the overall ethos of sustainability and sustainable living needs to pervade the whole program. This might not be simple to achieve if the program is being offered in the context often encountered in a traditional 'School' or 'College' of Engineering. Here courses are taught by a collection of specialists: mathematicians from a mathematics department, scientists from a different School or Faculty, and engineers of varying commitment to sustainability and sustainable living.

6. When to include ecological engineering

The previous sections have concentrated on an 'ecological engineering' curriculum for an undergraduate degree program. That such programs should be developed was one of the recommendations of a review paper (Mitsch, 1998) considering the development of ecological engineering in the 7 years following the first eponymous textbook in the field (Mitsch and Jørgensen, 1989). But that is not the only possibility.

Matlock et al. (2001), a group of USA agricultural, biosystems, and environmental engineers, concluded that developing an ecological engineering program to achieve professional credibility 'would require a significant shift in pedagogy that is difficult to accomplish at the undergraduate level.' They suggest that to achieve the 'substantive hybridization of science and engineering' that is their vision for ecological engineering, it would be best to build on an ABET-accredited, existing undergraduate program to provide the necessary engineering fundamentals. Then a postgraduate program, MS or PhD, would focus on ecological sciences and ecological design. This approach does not provide the desirable side-by-side integration in each year of the program.

A third timing possibility is to have a prior program in ecological sciences leading to an existing, professional engineering degree program. Perhaps the most obvious sequence is a college to university degree BS/MS sequence (USA); or a BSc/BE (Australia and New Zealand). This combination might take 5 years, but it too usually fails to provide the desirable 'horizontal' integration.

Only the first alternative timing of these three is able to satisfy fully the requirements implicit for 'ecological engineering' in the 'How to include' and 'What is in' sections above. The other two might be able to satisfy requirements for 'ecological' engineering. This conclusion results in particular from the stated needs to integrate courses in a 'vertical' sequence from science fundamentals, through applied engineering sciences to professional practice, with design and systems thinking progressing in level and complexity throughout the program. It also follows from the need for side-by-side integration of engineering and ecology, and the suggestion that sustainability needs to pervade the whole program.

An earlier version of this paper (Painter, 2001) was presented at the IEES Conference at Lincoln University, New Zealand, in 2001. A companion paper (Kirchner and Nairn, 2001) took a different approach to the content of ecological engineering, surveying the participants in a 1999 Ecological

Engineering Workshop on implementing 'ecological engineering as an academic career opportunity' and conducting an internet search for existing ecological engineering programs.

Kirchner and Nairn (2001) found six masters level programs: three in the USA, two in Japan and one in Germany. They found an additional six programs being proposed: four in the USA, one in Germany and one in New Zealand. One of these (University of Washington) was proposed as an undergraduate program and it seemed that the University of Georgia program was proposed to be for both an undergraduate and a graduate program. The University of Washington web site describes (November 2002) a Bachelor of Science in Forest Resources with a major in Forest and Ecological Engineering. The University of Georgia proposal does not yet seem to have been implemented at either level. As far as can be determined by these remote investigations, none of the programs in Kirchner and Nairn's (2001), their Table 1 is able to satisfy fully the requirements implicit for 'ecological engineering' in the 'How to include' and 'What is in' sections above.

Ideally, a whole-hearted approach to a new ecological engineering sub-discipline would favour implementation of an undergraduate program such as Mitsch (1998) has called for. Pragmatically, more success, sooner, might be obtained in a variety of academic institutions by developing ecological engineering as a specialisation within civil/environmental or biosystems (agricultural) engineering. This approach would also fit in with the earlier suggestion that different end-of-program practice contexts could well be appropriate in different regions and countries.

7. Example programs

There are already a number of undergraduate engineering programs which fulfil most of the requirements for ecological engineering practice, but which are not called 'ecological engineering'. Those mentioned here are restricted to the author's experience, mainly in Australia and New Zealand, but there might well be other examples, particularly in Europe.

The Bachelor of Engineering with Honours in Natural Resources Engineering (BE(Hons)(NR)) jointly taught by the University of Canterbury and Lincoln University in New Zealand is one such program (NREG, 2002). It is a four-year, professional engineering program accredited by the Institution of Professional Engineers New Zealand (IPENZ, 2002). It is awarded by the University of Canterbury alongside five other engineering degrees (Chemical & Process, Civil, Electrical & Computer, Forestry, Mechanical). The 'natural resources' involved include: water resources, earth resources, energy resources, waste resources and bioresources. Sustainability and sustainable living are core values in the program, with one recent (unofficial, this author's) definition of natural resources engineering echoing quite closely that quoted above for ecological engineering (Mitsch, 1996): 'Natural resources engineering is creative modification of ecosystems, to manage, use and protect natural resources, in harmony with human aspirations and sustainable quality of the environment.' The program has been offered since 1990 under this title; from 1969 to 1989 its predecessor was a BE(Agricultural). From 2004, the program will be awarded and taught entirely by the University of Canterbury.

There are many programs in environmental engineering in Australia and New Zealand, usually as a specialisation within civil engineering. One example is unusual in being an IPENZ-accredited, four-year program offered by an institute of technology, rather than a university (UNITEC, 2002). It is also unusual in its focus on the 'ethic of sustainability', and in its incorporation of biology, ecology, systems, ethics, environmental law and environmental impact assessment alongside more conventional environmental engineering courses.

Griffith University in Queensland, Australia, offers a joint degree in Civil Engineering and Environmental Science (GU, 2002), in which the engineering and science are integrated within each year of the five-year program. This overcomes the failing of most such programs, pointed out earlier. It has been suggested in this paper that countries might include appropriate engineering applications in addition to those usually associated with ecological engineering. This program has a particularly 'Queensland' flavour, as one applications context is coastal engineering.

There have been attempts in Australia and New Zealand in the last decade to provide other programs which would have fulfilled most of the requirements outlined for an ecological engineering undergraduate program. But some of these have failed, attracting insufficient student numbers to become economically viable.

8. Conclusion

Forty years after the environmental enlightenment of the 1960s is an appropriate time to seriously consider ecological engineering in both forms outlined here. Emergence and development of both an ecological engineering sub-discipline, and more ecologically aware engineers of other sub-disciplines, would enhance professional engineering and ecological science in their services to humankind and the rest of nature. For pragmatic reasons, ecological engineering could develop first as a specialisation of another sub-discipline, such as civil or biosystems engineering.

Ecological engineering is already, and should continue to be, distinct from environmental engineering. There was an urgent need for environmental engineering in the built environment once the extent of environmental degradation was realised from the 1960s onwards, in particular. It is a specialisation that bears within itself the seeds of its own destruction, and should become increasingly unnecessary as more ecologically aware engineers infiltrate all engineering sub-disciplines and specialisations.

It would be best if academic formation in ecological engineering could develop as an integrated (ecology/systems/engineering) undergraduate program pervaded throughout by a sustainability ethic. Some existing programs, undergraduate specialisations or integrated joint degree programs, come very close to what such a program would be, but are not called ecological engineering. More ecologically aware engineers of other specialisations and sub-disciplines could be provided through prior or post qualifications to existing engineering programs. This too is a pragmatic, rather than ideal, means of promoting ecological engineering in both of the senses considered here.

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