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Engineering Education and the New Industrial Revolution*

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The engineering profession is facing the greatest challenge of its history, a challenge that will determine its future. But the nature of the forces shaping this future, and the societal expectation of the role of technology can be deduced. Rate of change is a critical factor. The direction taken by engineering education will greatly affect the future of the profession. But the base for reform exists in work carried out in various parts of the world. The challenge can be met. What is needed is the will to make the change.

A RAPIDLY CHANGING CONTEXT

THE RATIONALE for a paradigm shift in the nature of engineering was set out in the documents of the United Nations Conference on Environment and Development [UNCED], particularly in 'Agenda 21'. Effectively, the objective of engineering has been redefined from 'development' to 'sustainable development', from the open and unfettered application of technology to the 'creative application of technology to achieve sustainable development', to quote from the vision statement of the World Engineering Partnership for Sustainable Development [1]. This objective has been endorsed as an engineering objective by the 1991 Arusha Declaration of WFEO, the WFEO Strategic Plan, the FIDIC Policy Statement of 1990, and subsequent policy statements by the AAES, the Engineering Council of the UK, and a number of other senior engineering institutions.

However, the engineering profession is not in a position to deliver on these new objectives, having fallen behind societal expectations since the 1970s. Twenty eight years and two world conferences [Stockholm 1972, Rio 1992] later, with environmental legislation spreading an expanding influence world wide, with the Montreal Protocol on protection of the ozone layer in operation, with climate change declared a near certainty, and major and observable trends towards clean technology and energy efficiency in every aspect of economic activity, most engineering teaching is still about the technological solution of technical problems, not about the context of the application of technology, now a clearly signalled societal expectation.

We have failed to acknowledge that we are practicing in dynamic, not static, circumstances driven by massive historical forces—the combination of population growth, resource depletion, and rising expectations of material living standards. Two observable features of engineering in a dynamic period are firstly, **lead time**, and secondly, **value change**. Engineers are familiar with lead time, but this applies in regard to teaching and training, as well as projects. An undergraduate entering engineering school in 1997, may not become a member of an engineering society until 2007. By this time world population will have increased by at least one fifth, ecological collapse of land-based and oceanic ecosystems will have extended, and cleaner production in industry will be advanced world wide. Ozone depleting substances will be phased out, and the Climate Change debate will have been determined, with large implications for policy. Investors will be insisting that cleaner production options for industry are fully investigated, and looking critically at investment in many established but environmentally suspect technologies when considering thirty-year investment periods. Industry and business will expect expert analysis of technological options. By this time the generating costs of wind and solar generation will be competitive with the generating costs of older technologies. The design of energy efficient buildings will be required by commerce as a matter of course. Re-use of materials, even in buildings and roads, will be moving into more general application. Most practicing engineers will routinely use engineer friendly databases and networks that are accessible world wide.

The foregoing scenario is for the short period of ten years. The question it raises is 'Will the graduate in ten years' time be equipped to enhance the contribution of the engineering profession in the circumstances described'? But first, is the scenario realistic? To make a judgement on this, it is necessary to consider not only technological trends, but also the societal driving forces that command the process.

Resources will continue to deplete. A recent report from the United Nations states that many

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parts of the world will face water shortage crises by 2010. The 1995 report by the Worldwatch Institute refers to rising population, over-harvesting of fish, depletion of forests, and over-use of groundwater resources. But it is estimated that world food production will have to increase 75 per cent by 2025 to equate to needs. In 2010 loss of biodiversity [currently estimated at 50 to 100 species per day] will, in spite of the Biodiversity Convention, be a major issue. The trend towards ever stronger environmental control will accelerate. At some stage environmental costs will become included in market costings. Of importance to engineering is the position taken by major business and industry. In 1996 this ranged from limited environmental awareness to far-sighted corporate objectives [2, 3]. By 2010 most major industry will be working to environmental objectives. And countries that have signed the Climate Change Convention will be well advanced in implementation of developed policy.

The UN HABITAT 2 Conference on Human Settlements, of June 1996, focused attention on the global danger represented by the growth of mega-cities. Most of the extra billion of population to be added in the ten years from 1996 to 2006 will be accommodated in cities. Cities are technological systems, and the engineers' responsibility for the infrastructures and living qualities of cities will increase.

By 2010, the relationship between environment and security will be clear, as poverty extends, and problems in meeting the needs of mega-cities compound [4]. The maintenance and enhancement of productive capacity, especially of the environments of poor countries, is a vital element of global security—a direct link between technological policy and global security.

THE PRESSURES FOR CHANGE

What does this combination of the direction of movement of social values [the driving forces], and the direction of movement of technology mean for engineering?

- The 're-orientation of technology—the key link between humans and nature', talked in 'Our Common Future' is under way and propelled by irresistible forces [5].
- The expected role of technology has been openly stated e.g. by UN agencies. Without technological reorientation, the goal of sustainable development cannot be attained. Engineering has a key role.
- Historical driving forces are such that the process will not stop if engineering does not deliver. But it may be slower, a vacuum may develop which will be filled by others, and the standing of engineering will further decline.
- The scale of change and challenge is such that the entire profession is involved. Lead time signals the need for unprecedented effort and unity of purpose. Practice and engineering education must work together.
- Key parameters of the new context of engineering are globalisation, continuous change in both practice and education, rise in the social value accorded to nature, increase of new technologies, and technological choice, and the need to monitor the relationship between technology and society.

THE NEW WORLD OF ENGINEERING EDUCATION

The policy statements of the engineering institutions have not greatly influenced education. Nor has there been much collaboration between practice and education. Changes in curricula initiated by educational institutions, have ranged from little, to course adaption, to a few bold efforts to equate education to the new situation.

In some countries, adaption has led to a wide variety of course options [6]. But while valuable as a first step in reorientation, it has two problems. The first arises from the belief that little could be left out of existing curricula. This has limited the extent of change. The second, with changes equated to perceived present requirements of the market, tends to overlook lead time.

It is efforts made to respond to the total problem that are of particular interest. Of these, the Georgia Tech programme at the Centre for Sustainable Technology is one of the most significant, with its acknowledgement of a new paradigm, lead time and rate of change, the environmental objective, and globalisation [7]. Priority actions in the programme were to develop a curriculum on sustainable development and technology, convene a workshop on metrics for measuring sustainability, research basic concepts and principles of technological sustainability, focus research on (and promote) technologies with immediate impact on sustainable development, and provide support services in policy planning and dissemination of sustainable technology.

An invited workshop on The Fundamentals of Environmental Education in Engineering Education was held in New Zealand in 1994 [8]. This concluded that the customers of engineers needed improved interaction, and that engineers needed additional skills and capabilities, and as well, to change their public image. A proportion must be generalists, and some specialist environmental engineering courses were required. The fundamentals for the environmentally educated engineer were a holistic approach, a clear vision of system functioning, appropriate attitudes, skills and knowledge, systems skills, interaction skills, broad knowledge in specific areas, and exposure to significant issues. All engineers should be environmentally educated, but there was a need also for what were described as 'environmentally involved engineers', for example, those who might be engaged in projects of large environmental significance such as a dam. There was need for fundamental early level courses to give students the direction on which to build the rest of their studies.

Among interesting developments in New Zealand has been a greenfields initiative in the setting up of a B.Tech.(Env.) degree at one of the country's largest polytechnics (see Appendix). Distinguishing features of this degree are that while engineering basics are taught, the programme also includes engineering context subjects. Students carry out research projects (case-based learning) ranging from industry collaboration in waste minimisation, to marine science studies that could be categorised as applied natural science.

These examples, other initiatives, the adaptions, and work by agencies such as UNEP and UNESCO represent a reconnaissance of new directions that can be an adequate base for a general advance. Some of the requirements for the future seem to be:

- A strong platform of environmental education for all engineers, including a sound understanding of sustainability, and a good general knowledge of global issues.
- An ability to take a holistic approach with a clear vision of system functioning (including natural systems) and ability to take systems approaches.
- Routine familiarity with EIA and LCA, and the ability to use these, not only as tests of technology options, but also creatively as analytical tools.
- For practice in a period of rapid technological change, greater emphasis on principles of engineering science, and less on established technologies.
- Ability to select technology that is appropriate to a given economic, social, environmental, and cultural context.

BUILDING CAPACITY TO MEET THE CHALLENGE

The scenario for 2006 has presented a central argument. Excepting bolder initiatives, the general direction of education cannot meet the requirements of that scenario. This can only be done by a determined effort from a united profession, aimed at a specified outcome by a specified time. This situation is familiar enough to engineers involved in major projects.

Objectives have been set out by the engineering policy statements. Scoping of new parameters exists in the work described in the preceding section. A review of all this work can provide guidelines and objectives for the formation of engineers by, say the year 2010. A target date is needed to capture the 'drift' that leads to a continuous falling behind. It will also programme the implementational steps. It is implementation, rather than policy statements that requires planning, timetables, commitment, resources, sustainable leadership, and determination.

It is fundamental to implementation that steps in education lie within a whole of profession strategy. Reasons for this include the issues of lead time and scale of change that have already been discussed. Others relate to the situation brought on by rate of change; e.g. the practitioners who are operating at the leading edge (of cleaner production, energy efficiency generally and in building design, wind and solar technologies, sustainable cities etc.) are mostly (but with some exceptions) within industry or consulting, (FIDIC has been a leading advocate of new policy) and not within the teaching environment. The resources of the whole profession need to be mobilised for change. There are the large numbers of 'in-practice' engineers who will wish to have access to new information within professional development. Importantly, there are the structured institutional relationships with education via accreditation, training, and election. Without education, institution policies do not become reality. But without the seal of accreditation, education does not become the route to election into a professional engineering association. The Standing Committee on Environmental Engineering of the Institution of Engineers, Australia, has developed draft 'guidelines for including a sustainability ethic into single-discipline engineering courses' [9].

A step in the building of capacity is currently being planned by the Industry and Environment Office of the UNEP, the World Business Partnership for Sustainable Development (concern about engineering education is not confined to engineering), and WFEO. The working conference is to be an invited workshop of perhaps sixty people, selected world-wide, aimed at specific outputs:

- To help educators teach more effectively for the production of environmentally educated engineers.
- To understand the characteristics of the product, that is, the attitude, skills and knowledge of the environmentally educated engineer.
- To agree on fundamental principles of how to teach so as to form the desired product.
- To give participants examples of successful initiatives, curricula and academic case studies.
- To provide case studies of environmentally sound engineering and sustainable development.
- To provide guidelines and tools for course development.
- To initiate a network for the regular exchange of information and experience, and for the generation of collaborative projects.

The need for new profession dynamics, strategies, and capacity building, was foreseen in 1991 (WFEO 'Arusha Declaration') in the form of proposed small centres for capacity building at global, regional, and national levels. As a regional example, in the South East Asia/Pacific region, the Federation of Engineering Institutions of South East Asia and the Pacific (FEISEAP) is near the pilot stage of a network linking national members, a number of whom are already advanced with their own operating networks. The FEISEAP network will be able to deliver educational courses (and a wide range of technology information and data bases) at the regional and national level. It will be co-ordinated with the global WeNet, under development by the World Engineering Partnership for Sustainable Development.

As an example of national level strategy development, the Institution of Professional Engineers of New Zealand has involved all sectors of the profession in the preparation of an action plan *to make sustainable development an explicit part of all facets of IPENZ activity*. The critical point here is that until national level engineering societies decide to implement action on their policy statements, the policy/accreditation/academic programme linkages that relate education to the broad goals of engineering cannot operate with the sense of direction and certainty that is needed. IPENZ is preparing a proposal inviting offers for the establishment of a centre for sustainable management (CSM), to act as the driver for specific elements of the action plan. As it is anticipated that offers will come from education institutions, the linkage between institution policy and education will be reinforced.

The CSM would be responsible for implementation of specific components of the action plan requiring:

1. *Increase in members' competency in sustainable management* (education programmes for current members and mentors, organisation of workshops etc., and fostering information exchange on sustainable technology, processes and methods).
2. *Promotion of the development and application of technologies and processes which will promote sustainable management of natural and physical resources* (Research into SD, information dissemination, sustainable technologies, resource limits, ecological economics, Cleaner Production case studies, codes of practice and guidelines, etc.).

The CSM, when established, would become the national member node in the FEISEAP regional network.

CAPACITY AND THE UNIVERSITIES

The UNEP Cleaner Production Programme, beginning in 1990, has exercised world-wide influence. But it was apparent before the review in 1994 that a limit to expansion of the programme lay in the numbers competent to teach cleaner production. How many universities run comprehensive courses on cleaner production, including life cycle analysis, active involvement with industry, and research?

The Norwegian Society of Professional Engineers (NSPE) contracted to the Norwegian Government to implement environmentally favourable and financially profitable restructuring of industrial processes in 200 to 350 production companies in Poland and the Czech and Slovak Republics. The educational goals of the programmes were to educate a minimum of 35 native instructors in the first programme cycle, then over the next three years for those instructors to train new instructors (from 300 to 500) to act as advisers for assessment projects in participating industry [10].

These two examples illustrate the nature of fundamental problems—judgement of market requirements, and the availability of suitably trained people. (Some of the graduates from the NSPE training programmes are now instructing in CP in universities). That it is the general thesis of this paper that *there is a mismatch between education and the market* will be clear. What can be done at the level of the university faculty, the critical agent of the desired change? As nothing will happen without motivation and commitment, a faculty will wish to examine the evidence that change is needed, that rate of change is a real phenomenon, and that the market requires new products. Wide consultation is essential, with the market on the one hand, with the engineering society to maintain a perspective on accreditation and policy, and with agencies like UNEP actively working in education reform. Assuming then that motivation, conviction, and faculty agreement are present, the will to change exists, and change can be initiated. The faculty may be ready to consider a declaration of principles like those currently before the faculty of the School of Engineering of the University of Auckland, aimed at making sustainability the basis of all faculty teaching, and of the following implementational strategy [11]:

Element 1: That all staff within the School commit themselves to incorporating into teaching and research (where relevant, appropriate, and practical) concepts, information and guidelines consistent with moving toward an ecologically sustainable future, and that such commitment be formalised within a Declaration of Principles.

Element 2: That an environmental and sustainability audit be undertaken to all existing and proposed new courses for the new BE to facilitate the development of relevant and appropriate supporting concepts, guidelines and materials to assist all staff in implementing Element 1.

Element 3. That a programme of environment/sustainability workshops be organised on an ongoing basis of supporting staff into incorporating sustainability issues into teaching and research.

Element 4. That a course in Environmental Principles for engineers be introduced within year

1 of the new BE complement the teaching of Engineering Principles, and to provide the foundation for subsequent environmental and sustainability content throughout years 2, 3, and 4.

Element 5. That where relevant, appropriate and practical, design teaching across all disciplines be enhanced and/or restructured to incorporate sustainability principles, including *inter alia* cleaner production, life cycle assessment, industrial ecology.

Element 6. That the School promote and encourage research activity in the area of sustainability in engineering practice.

Element 7. That a special award be established to recognise innovation within the School in teaching and research in sustainability through engineering.

Element 8. That the School Plan be reviewed annually to ensure that education and research in engineering is centred on the sustainable management of natural and physical resources.

Such a programme will require lecturers to more than keep abreast of efforts in sustainable development, and to initiate best teaching practices for the purpose. But it deals with much more—the fundamental issue of attitude formation, a major weakness of the present wherein environment is so often presented as an add-on, or optional extra. The undergraduate is in a learning situation where all activity is referenced to the changed paradigm referred to at the beginning of the paper.

Enhancing and restructuring teaching to incorporate sustainability across all disciplines, is a challenge that will require a lot of study of sustainability. It is a challenge that raises several questions, and amongst others:

1. The availability of teaching material.
2. Assistance from the profession in practice, and elsewhere.
3. Training.

An apparent shortage of teaching material is more lack of knowledge about where to access teaching material than shortage. There is a vast range: the library of environmental texts expands daily, and CD-ROMS less frequently. There are frequent conferences on environmental topics, technology groups confer, network, and publish newsletters, international agencies publish teaching materials and training packages. (FIDIC has also published a training kit), and databases, new technology information, and more general material on sustainable development and environment is available on the Internet. There are journals, networks, and conferences.

Current re-orientation to environmental objectives is not confined to technology. It affects science, planning, economics, law administration, and commerce. As with engineering, there are practitioners working in the front edge of every field who can contribute knowledge and experience to lectures, seminars, and case-work, once the shape and direction of programmes have been decided. There must be scope for visiting lecturers from consulting offices and environmental administrations, other university disciplines (e.g. ecology, social sciences), industry, exchange arrangements with other faculties, joint industry/university research projects, and increased case-directed learning.

UNEP Train the Trainers activities have focused in five directions [12]. Since Training the Trainers, in the engineering profession situation described in this paper, should become a whole of profession endeavour, it is useful to note the areas of focus of the UNEP.

The training packages are neither textbooks nor courses, but they provide a model for trainers to develop their own material. They help the trainer to focus on environmental skill building through interactive group work, case study analysis, practical problem solving, and simulation studies. The five areas of focus are:

1. The creation of resource packages for tertiary institutions covering priority Agenda 21 subjects such as cleaner production, industrial accidents, hazardous waste management, phase out of CFC's, and specific important industry sectors such as mining, tanning, textile production, and breweries.
2. As practical environmental skills are better learned through practice and simulations than through lectures, the UNEP packages are based on interactive, problem-solving formats of teaching.
3. The construction of networks is an essential dynamic of change.
4. Links with corporate and business management.
5. Links with the other international organisations [e.g. WHO, ILO, UNIDO] that are also building databases and producing teaching material are necessary.

SUMMARY

The engineering profession is facing the greatest challenge of its history, a challenge that will determine its future. But the nature of the forces shaping this future, and the societal expectation of the role of technology can be deduced. Rate of change is a critical factor. The direction taken by engineering education will greatly affect the response of the profession. But the base for reform exists in work already carried out in various parts of the world. The challenge can be met. What is needed is the will to make the change.

REFERENCES

1. D. A. Thom, The New Technical Culture, in Aiming for Quality in Engineering Education (ed. R. M. Sharp, H. Silyn Roberts) *Proc. 5th Annual Convention and Conference, Australasian Association for Engineering Education, Auckland, New Zealand, 12–15 December 1993*, pp. 430–439
2. Helen Howes, A Canadian utility's experience in integrating sustainable development into its planning and decision-making framework, *Int. Conf. Engineering and Urban Sustainability, Budapest, Hungary, October, 1995*.
3. Network for Industrial Environmental Management, *Advancing Towards More Environmentally Adapted Processes in Swedish Mills*. NIEM Newsbrief No. 7 (Feb. 1996).
4. Terence O'Brien, Sustainable Management of Our Environment and Resources, *New Zealand Engineering*, March 1996.
5. World Commission for Environment and Development, *Our Common Future*, Oxford University Press, p. 60 (1987).
6. G. C. Dandy, and T. M. Daniell, A review of undergraduate environmental engineering degrees in Australia, *National Conference on Environmental Engineering, Institution of Engineers, Australia*, Pub. No. 92, pp. 59–64 (1992).
7. Center for Sustainable Technology, Georgia Institute of Technology, *Progress Report 1994*, World Engineering Partnership for Sustainable Development.
8. D. Elms and D. Wilkinson, (ed). The environmentally educated engineer—focus on fundamentals, *Proc. Workshop on Fundamentals of Environmental Education*, Centre for Advanced Education, University of Canterbury, New Zealand, March 1995.
9. National Committee on Environmental Engineering, the Institution of Engineers, Australia. *Draft Guidelines for Accreditation of Environmental Engineering Undergraduate Courses.*
10. Olar F. Nedenes, Transfer of industrial knowhow, *UNEP Third High Level Advisory Seminar on Cleaner Production, Warsaw, Poland, October, 1994*.
11. I. W. Gunn, Education for sustainability through engineering, *First International Conference on Environmental Engineering Education and Training, EET 96, 17–19 April, 1996*, Wessex Institute of Technology, Southampton, UK.
12. UNEP, *Train the Trainers in Environmental Management in Industry*, Overview of UNEP Activity.

APPENDIX

Establishing the platform of Environmental Principles within Engineering Degree programmes, two examples.

1. *UNITEC Institute of Technology, Auckland, New Zealand*

First Year	Web of Life
	Environmental Chemistry
Second Year	Sustainable production
	Surficial Processes
	Sensitive Environment
	Systems
	Hazardous Goods & Waste
	Climatology
Third Year	Philosophy, Ethics, and Science
	Environmental Law
	Water and Soil Conservation
	Geographic Information Systems
Fourth Year	Waste Minimisation
	Env. Impact Assessmt
	Regional Studies

Student Research Projects in Cleaner Production and Marine Science.

2. *School of Engineering, the University of Auckland*
Year 1, all disciplines

- Earth systems: Introduction to geology, ecology, economy; geosphere, biosphere ecosystem cycles.
- Sustainability concepts: Ecosystem function, entropy and the laws of thermodynamics; ecosystem stability, biodiversity and ecological sustainability.
- Ecosystem dynamics: Community structures; diversity and stability; food webs and biomass energy; population growth and management; carrying capacity; biotic potential and environmental resistance; ecosystem response to disruption and change; human impacts and ecosystem adaption; ecosystem models.
- Human ecosystem interactions: Urban, agricultural, forest, ocean and industrial ecosystems and their interactions; introduction to ecological implications of resource use; conservation and preservation.
- Engineering and the environment: Assessment of environmental effects: social and cultural views of the environment; design with nature; sustainable cities; energy, water, minerals and biological resource use; residue management; case studies in environmental impacts of engineering activity.