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A Proposed Course Matrix for Holistic Education in Environmental Engineering*

D. G. WAREHAM
Department of Civil Engineering, University of Canterbury, Private Bag 4800, Christchurch, New Zealand
P. ELEFSINIOTIS
Department of Civil and Geological Engineering, University of Manitoba, Winnipeg, Manitoba, Canada R3T 5V6

The fragmented nature of many undergraduate environmental engineering programmes can be directly attributed to the lack of formal acceptance of environmental engineering as a speciality in its own right. In many cases, environmental engineering programmes have been formulated by combining appropriate courses from single disciplines, such as existing civil and chemical engineering programmes. The absence of (i) a clearly articulated philosophical base (which ties the programme together), and (ii) a well-defined set of foundational skills (widely agreed upon by educators) results in an environmental engineer who does not match the needs and expectations of society. This paper explains the rationale for a broad, yet deep, educational curriculum designed to impart to students a foundational series of environmental skills tuned to the holistic nature of environmental engineering. A sample instructional matrix is attached which purports to impart these skills to the prospective student.

THE NATURE OF ENVIRONMENTAL PROBLEMS: PRESSURES FOR CHANGE

DURING the last 30 years society has become increasingly aware that the earth has sustained enormous stresses. The escalating demand for energy and natural resources has been augmented by burgeoning population growth and elevated standards of living. The present environmental crisis can be ascribed to the imposition of economic activities on ecological systems with little regard for the latter's physical limitations. Development without restraint directly undermines the potential for continued development through (i) over-exploitation of natural resources, and (ii) discharge of residuals [1]. The rate and magnitude of exploitation has been amplified in recent years because of (i) expanding populations and (ii) technological changes which have enabled individuals to access and deplete more resources within a shorter unit of time [2]. The prognosis from the evolutionary history of developed countries is that less-developed nations will have little regard for the destruction of natural habitats as they seek to advance their own economies [3]. This will result in further deterioration of environmental quality and an ever-worsening environmental crisis.

Environmental problems are also increasing in complexity, and as such they demand solutions that require a broader understanding of the fundamental scientific issues underlying pollution. Environmental impacts previously thought to be local in scope are now seen to be global in scale. It is no longer sufficient, therefore, to enact provincial regulatory controls, since environmental contamination frequently crosses international boundaries. Similarly, technological solutions are often inadequate in and of themselves because they reflect an end-of-pipe, reductionist mindset, which believes that the ability to reduce a problem to technological terms leads to an ability to solve the problem on strictly technological grounds. The flaw with this attitude is that it fails to question the nature of the human activities which generate the pollutant in the first place. Human behavioral changes, waste management techniques, elimination or reduction at source, in-house preventive measures and/or iterative process modifications may actually be a more realistic way forward in order to remedy many environmental problems.

Judging from the number of recent engineering conferences with environmental themes, it is clear that environmental engineering educational programmes are coming under increasing pressure to supply the marketplace with a new kind of environmental engineer. This engineer must be better able to handle multi-faceted, large-scale environmental problems, including the transportation of airborne pollution, contaminant dispersion in the ocean, global warming, ozone depletion, deforestation, loss of biodiversity and desertification. It is clear that such phenomena pass beyond regional and provincial jurisdictions. These types of problems also no longer possess crisp technical boundaries requiring the expertise of one particular kind of

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engineer. Most problems must be looked at in their totality and this may require sophisticated technical knowledge related to multi-media contamination, including complex chemical, biological and physical reactions. It is well known, for example, that traditional civil engineering does not prepare a student well in these areas [4]. Moreover, since environmental problems occur in the public domain, there is a need for a deep integration of the social sciences, public policy development, economics, environmental law and environmental impact assessment. The new type of environmental engineer must therefore have expertise in many of the above areas, some of which may play a crucial role in enabling engineers to address adequately the full scope of environmental problems.

The changing nature of the environmental crisis provides a pressure for change with respect to the nature and course structure of existing environmental engineering educational programmes. This is also in line with the world-wide interest and re-evaluation of the very nature of engineering education [5].

ENVIRONMENTAL CONSCIOUSNESS AND ENGINEERING EDUCATION

Perhaps the most successful way of influencing human behavior, perceptions, attitudes and values is education. Since engineers are involved in changing the environment, it is particularly appropriate that environmental protection and proper utilization of environmental resources be taught within the context of an engineering education [6]. Engineering techniques must be developed to manage intelligently both the natural resources and the residuals associated with economic development. The governing principle is that human life (both present and future) must not be jeopardized. This principle has been embodied in the term 'sustainable development', loosely defined by the World Commission on Environment and Development (1987) to be 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' [7].

It is extremely desirable therefore that a *sustainability ethic* pervade all engineering fields. The goal of engineering programmes should be to produce engineers who are both technically competent and environmentally conscious [1]. Sustainable development can be thought of as an environmental ethic with two components—one targeted to pollution prevention and one targeted to pollution remediation. The first element refers to a belief that environmental impact assessment, environmental auditing, waste minimization and lifecycle analysis courses should be incorporated into all engineering programmes regardless of discipline. These courses should be taught within the philosophical context that economic development is tied to principles of equity, social justice, environmental responsibility and accountability.

Courses such as these should be designed to instill within the student a pollution-prevention mindset by weaving the concept of sustainability into the development and design process. The traditional concept of development has essentially been a compromise between what is technically feasible and what is economically attractive [8]. Within the framework of pollution prevention, an additional factor that now must be considered is whether the technology is acceptable on environmental grounds [8]. Such an environmentally integrated approach recognizes that the engineering profession at large has an obligation to meet environmental stewardship goals, especially as they relate to the development of new technologies.

The second component of a sustainability ethic is the cultivation of a sense of moral values, specifically related to pollution remediation. Vesiland [3] is essentially referring to this when he states:

> public opinion has evolved to where the direct and immediate health effects of environmental contamination are no longer of primary concern. The cleanliness of streams, not only for the benefit of human health, but also for the benefit of the stream itself has become a driving force, and legislation has been passed that does not focus directly on human health but instead addresses our desire for a clean environment. Protection of wildlife habitat, the preservation of species and the health of ecosystems have become valid objectives for the spending of resources. Such a sense of mission, unrelated to human health, is often referred to as an environmental ethic, which is a major driving force of modern environmental engineering.

It can be seen, then, that environmental engineers have an additional responsibility to be at the forefront of movements to clean up pollution, even pollution that does not have a direct link to public health. This takes the form of an ethical imperative because pollution-remediation is seen as the moral thing to do (rather than the necessary thing to do because of human health concerns).

A solid grounding in environmental ethics is what should be the first of the foundational courses of an undergraduate environmental engineering programme. Engineers may feel uneasy about designating an ethics course as a fundamental skill. This is because the course requires substantially less (or a different degree of) rigor than traditional engineering courses. It is worth asking, however, whether the current environmental crisis has arisen because environmental ethics has been perceived in the past as peripheral to engineering rather than the foundation upon which it is built?

Before outlining some additional fundamentals (and moving on to a specific instructional matrix) it is necessary to examine briefly the evolution of existing environmental engineering programmes. The reasons for this are twofold. Firstly, much of what has already been developed can be conserved. Secondly, it is necessary to understand the evolutionary process of the most dominant paradigm before making any attempt to revise or improve it.

THE EVOLUTION OF ENVIRONMENTAL ENGINEERING AND THE NEED FOR CONTINUED ADAPTION

Environmental engineering has a heritage stretching back many years. Its foundation is embedded in the oldest class of engineering devoted to improving the human environment. This category is known as civil engineering, a title first officially used by John Smeaton of Great Britain in the latter half of the 18th century [9]. In sharp contrast to the earlier military engineer (who devised infrastructure—and machines—to enhance warfare), the civil engineer has a name which connotes its mandate; that being the development of infrastructure for general public use.

The first engineers with a knowledge of subject material linked to modern environmental engineering were engineers with expertise in applied hydraulics. Called upon to provide an adequate supply of water for a multitude of purposes, these early engineers understood the necessity of investigating the quality of the supplied water, even though it was much later before it became scientifically proven that water could carry pollution and disease. For example, the main function of the Roman aqueduct built by Marcus Agrippa (63–12 BC) was to supply water for the baths at the city of Nemausus (modern day Nimes in France). In addition to the hydraulic design (low-pressure, continuous gravitational flow), the Roman engineers carried out tests to examine the quality of the water delivered from the springs near Uzes. Settling tests were used to ascertain the quantity of silt (to alleviate sedimentation concerns), while evaporation tests were conducted to check the water's mineral content (traces of calcium deposits were found). In addition, mammals, birds and fish (both from the source and nearby) were killed and dissected to see if they were relatively free from disease [10].

Centuries later (in 1854), Dr John Snow definitively established the link between contaminated water and health via an epidemiology study correlating cholera outbreaks with sources of water supply [11]. Many waterworks systems at this time coincidentally began to include filtration units in order to remove turbidity. In 1892, Robert Koch established that filtration units also provided protection against disease [11]. Filtration was followed by coagulation and flocculation and finally by chlorination in 1908.

In the late 1800s, society had also begun to realize that used water contained contaminants which should be treated before discharge to the natural environment. This led to significant advances in the area of wastewater treatment and ultimately to the birth of the subdiscipline of civil engineering known as sanitary engineering in the United States and public health engineering in the United Kingdom. In the 1970s, the name was changed to environmental engineering to reflect the realization that public health could be influenced by much more than municipal wastes. It was increasingly evident that a wide variety of industrial, toxic and hazardous wastes could have both short-and long-term effects on human health.

The name change produced a degree of tension because the word *environmental* connoted a much more holistic approach than was actually in evidence in many programmes. Although the option was given to the students to specialize in an environmental stream in their upper years, this belied the fact that many programmes were still fundamentally water-based in their consideration of the environment. To alleviate some of the tension, the master's degree in environmental engineering was developed. This allowed graduate students the flexibility of enrolling in additional courses outside the domain of civil engineering. Single-discipline approaches tend, however, to be too narrow in perspective, since they train professionals to deal with only a subset of environmental problems, such as air pollution, water pollution or hazardous wastes [12]. In the 1980s, undergraduate environmental engineering programmes started to appear, most of which were formed by combining the most appropriate courses from the civil and chemical engineering disciplines. Although these rightly should comprise a substantial portion of the education of an environmental engineer, they suffer from many of the same problems as single-discipline undergraduate and masters's degrees.

The basic problem with an amalgamation approach is that it tends to be reactive rather than proactive. This is especially so if the courses are reshuffled without the commitment of additional resources. Moreover, these types of programmes tend to be fragmented because environmental issues are not treated in an integrated, comprehensive fashion subject to an underlying philosophy which cohesively ties the programme together. In addition, both chemical and civil engineering predominantly represent the process side of engineering (whether they be in-house modification or end-of-pipe processes). This is still fundamentally an outlook which considers environmental problems as local phenomena to be alleviated by the application of isolated technologies.

There is already some evidence [13] which suggests that an environmental course is far more successful when run from a specially formed, multidisciplinary department rather than from coordination of established science or engineering departments. The product of this type of programme tends to be flexible enough to move easily from one function to another, interpreting diverse disciplines and perspectives. The fact is, environmental problems and solutions are multi-disciplinary by nature, and this needs to be reflected in environmental engineering education [14]. It is clear, then, that territorial claims should not prejudice the natural ability of environmental engineering to evolve. Protectionist measures are fine if they are used to preserve what is good, but they can also be stultifying if they prevent the creation of an environmental engineering degree which truly reflects the holistic nature of environmental problems.

THE NATURE OF AN UNDERGRADUATE ENVIRONMENTAL ENGINEERING DEGREE

It might be argued that the interdisciplinary nature of environmental problems prevents the formation of a single-discipline programme purporting to cover the major aspects of either environmental engineering or environmental science. This comes from a recognition that many environmental problems can be validly approached from a variety of either science-based perspectives or engineering-based perspectives (or some combination of both). A typical example in the water quality domain is the protection of the water environment. A recurring question is whether protection of water bodies should be based on effluent standards or receiving water quality. Although intertwined, these fundamentally represent two different philosophical approaches.

Setting water quality standards based on the natural ability of the receiving water to accommodate pollution (and eliminate it through dilution and/or natural purification processes) is fundamentally a science-based approach. To be certain, engineering knowledge cannot be discounted, especially that associated with advection and dispersion. It is maintained, however, that engineering knowledge is of secondary importance if the toxicological (i.e. scientific) effects (both short-term and long-term) on biota of any given concentration of pollutant cannot be accurately assessed. If these effects cannot be realistically quantified, then technological solutions are inadequate in and of themselves. This is also true of epidemiology studies, for if the true effect on health of low concentrations cannot be scientifically proven, the validity and extent of control strategies is open to debate.

In contrast, setting limits on effluent discharges is fundamentally an engineering approach, because it involves applying the best available (or practical) technology (an engineering/economic decision) to reduce pollution at the source. The approach must, of course, consider the natural assimilative capacity of the receiving water; however, essentially the engineer first applies a technological (i.e. artificial) solution, before making use of whatever assimilative (i.e. natural) capacity possessed by the stream.

This example underscores the close link (and sometimes blurred distinction) between environmental engineering and environmental science. It is necessary, therefore, to highlight some of the distinctive characteristics distinguishing engineering from science in order to argue effectively for an undergraduate environmental engineering programme (incorporating many science-based courses) rather than vice versa. To do this properly, it is necessary to examine the characteristics that allow undergraduate engineering programmes to be sanctioned by professional accreditation boards.

For an undergraduate engineering degree to be accredited, it typically must satisfy specific criteria with respect to course content, entry standards, teaching staff, teaching methods, professional interaction, examination procedures, and facilities for teaching, research and students [15]. The two most difficult conditions for an undergraduate environmental engineering degree (permeated with science-based courses) would be (i) the course content and (ii) the professional qualifications of the teaching staff. The latter criteria would be particulary difficult to resolve, primarily because many of the staff teaching science-based courses would not necessarily be registered professional engineers. It might be possible to set target ranges stipulating optimum ratios for the proportion of engineers to scientists; however, realistically the better way forward would be a tacit recognition by engineers that scientists are the best professionals to teach science-based courses, simply because they possess the requisite depth of knowledge.

Given the right vision scientists can supply much of the needed science background *within* a context of how engineers use science information to make engineering decisions. For example, where appropriate, science-based courses could lend themselves towards consideration of large-scale phenomena, rather than the micro-orientation which has been the trend in natural sciences in recent years. It is important that this vision be supplied in a deliberate manner (with iterative feedback), otherwise the result will be a fragmented programme in which the science-based courses fulfil a service role rather being an integrated part of a comprehensive environmental programme. This stands in contrast to the more common method, which tends to incorporate science courses as peripheral and/or serial options. Such an approach does not lead to the development of a holistic environmental engineer.

With respect to the course content, it is important to consider the philosophical principles by which accreditation boards recognize an engineering degree. The first of these principles is that the programme must expose the students to sufficient breadth in engineering. In other words, the students must be suitably grounded in an accepted group of fundamentals which underpin a particular engineering discipline. This goes far beyond an integral understanding of mathematics and natural sciences. For example, civil engineers must have a deep understanding of the nature and strength of materials used in creating structures. They must also have an understanding of the ways in which forces and stresses are transmitted. The fundamentals of civil engineering therefore include courses in mechanics (solid and fluid mechanics) and the strength of materials.

It is necessary, therefore, to similarly define subject material which underpins environmental engineering. This paper has already alluded to the inclusion of environmental ethics as a fundamental—both a pollution-prevention (sustainable technology) and a pollution-remediation ethic. A second course which should be considered as a foundational course is communications (both oral and written). The resolution to many environmental problems lies on the interface between technology and policy. There is, therefore, a real need to train environmental engineers to communicate with a wide range of experts operating in the arena of environmental concerns. Because of the political sensitivity of environmental issues, an environmental engineer needs to be particularly adept at negotiation and conflict resolution skills, especially as they relate to communicating with special interest groups. It is important that the environmental engineer be able to clearly articulate rational environmental policy in keeping with the sustainable development principles outlined earlier. Again engineers may feel uncomfortable about classifying a non-technical subject as a fundamental of engineering; however, the changing nature of environmental problems demands a type of engineer competent in social interactive management skills. To overlook the importance of excellent communication skills in environmental engineering shows a lack of foresight and understanding of the environmental marketplace.

It is important, of course, to define a set of foundational subjects which possess a certain degree of technical rigor. One of the most promising suggestions in recent years is systems analysis [16,17]. Systems thinking developed as a reaction to the atomistic way of examining phenomena in the scientific and engineering world. Systems thinking is very much in tune with the holistic nature of environmental engineering because it reassembles bits and pieces of information to form a comprehensive whole. Environmental problems are typical of problems where technology interacts with the natural or social environment. As such, the objectives are multiple and diffuse (rather than single or precise) with the appropriate measures of environmental impact not easily quantifiable [16]. An environmental engineer needs to be grounded in the nature and behavior of complex systems to give him or her the ability to evaluate a problem that involves accurately interpreting the relevance of individual components of information (a large portion of which may be piecemeal scientific observations). A systems perspective is necessary to weave the data into a comprehensive whole, and to provide a quantitative framework from which an engineering decision can be systematically extracted.

A second foundational skill requiring rigor is the ability to model accurately environmental problems [18]. The environmental engineer should be particularly good at constructing conceptual, mathematical and physical models which realistically represent the interaction between a variety of environmental effects. Armed with a knowledge of the system behavior (and recorded measurements if any), the student should be able to see the similarities and differences between a model, any mathematical simplifications to the theory, and the behaviour of the real system itself. The student will then be in a position to develop either more detailed physical or conceptual models and/or more complex mathematical procedures to quantify the behavior of the system [19]. The models must be able both to explain the observed data and predict the outcome of various interactions, especially as they relate to either process-related improvements or pollution-remediation techniques. Again the emphasis is upon the production of quantitative information which can be used as the basis for selection of pollution-prevention and pollution-remediation schemes.

In general, the second philosophical principle behind accreditation is that the students be exposed to sufficient depth in a particular branch of engineering. Sufficient depth is necessary so that engineering judgement can be made regarding design. Design is the factor which lies at the heart of the boundary separating engineering from science. Depth is probably the more difficult criteria to satisfy because an acknowledged criticism of environmental engineering programmes is that the cross-fertilization of disciplines sacrifices depth. The underlying impetus behind depth, however, is public protection from incompetent engineers. For example, the primary reason behind the inclusion of standards in design manuals is so that quality control can be maintained over a set of design principles and practices.

If the reason for depth is protection of the public, then there are other ways than serial, lecture-based, coursework methods for achieving depth in a particular engineering discipline. Environmental depth can be obtained by devising practice-oriented courses that rigorously and repeatedly expose the student in a systematic fashion to individual and multi-media environmental problems. Such courses go far beyond examining traditionally appropriate remediation technologies. For example they must give credence to the consideration of self-organized systems, such as lightly managed ecosystems [20]. Repeated and early exposure in a practical setting to existing and innovative environmental technologies (and the cost/benefits associated with prevention/remediation) will enable the student to have the confidence to move to the step of synthesis which lies at the heart of design.

A fundamental characteristic that makes the engineering sciences different from the natural sciences is that they require a strong feedback from engineering practice [5]. This is the crux which can provide the necessary depth in environmental engineering. As long as the loop is closed (i.e. there is continuous, iterative interaction) between practitioners and educators, the product of an undergraduate environmental engineering programme will be competent to solve and provide innovative solutions to environmental problems. As much as possible, most courses should provide opportunities for strong interaction with practitioners of environmental engineering. Rather than completely consisting of extensive lectures, a course should include seminars, group discussions, case studies, site experiences and project presentations [21], all designed to expose the students to practical engineering solutions to environmental problems. It is important to turn the courses into an active-learning mode in which more than just information is transmitted. The use of role-playing in debating environmentally sensitive issues may be particularly useful here. Presentation of environmental material should be tied to mechanisms for comprehension of the data, its significance and its impact on the individual's education and value to the community [22]. There is no greater need for this to be true than in an undergraduate environmental education curriculum.

UNDERGRADUATE ENVIRONMENTAL ENGINEERING PROGRAMME CONTENT AND STRUCTURE

The entrance degree to environmental engineering has traditionally been at the master's level [22]. It might be suggested that a master's programme of study should entail subjects which contain a large degree of complexity. A reflective analysis of the evolution and content of most environmental

Table 1. Core courses for environmental engineering curriculum

Year/Semester	Title of Course
Year 1 1st Semester	Algebra and Vector Geometry Calculus I Technical Writing and Communication Skills Physics for Engineers General Chemistry for Engineers Environmental Ethics
Year 1 2nd Semester	Probability and Statistics Calculus II Introduction to Computing in Engineering Introduction to Engineering Practice Concepts of Mass Transfer and Materials Balance Engineering Economics
Year 2 1st Semester	Advanced Calculus Thermodynamics Environmental Biology Fluid Mechanics Water and Air Environmental Chemistry Ecological and Environmental Systems
Year 2 2nd Semester	Environmental Impact Assessment Environmental Resources Management Differential Equations Water and Wastewater Quality Management Organic Chemistry and Biochemistry Environmental Microbiology and Toxicology
Year 3 1st Semester	Environmental Policy and Law Environmental Hydrology and Hydraulics Systems Analysis Environmental Monitoring and Modelling Techniques Introduction to Biotechnology Soil Mechanics and Geology for Environmental Engineers
Year 3 2nd Semester	Environmental Risk Assessment & Analysis Numerical Methods in Engineering Analysis Water Resources Systems and Planning Operations Research Contaminant Transport Processes Hydrogeology and Environmental Geotechnology

engineering programmes will find that (i) the material for most environmental engineering subjects is not necessarily complex, and (ii) the master's entrance level requirement is an artificially erected boundary, set primarily because the student has been constrained to satisfy accreditation requirements for other undergraduate degrees (such as civil or chemical engineering).

In order to market a fully fledged holistic undergraduate environmental engineering programme, the graduate must be sufficiently differentiated from the single-discipline product. Thus, the following pattern of university education may not necessarily satisfy any current accreditation guidelines for a bachelor's degree. Consistent with the breadth and depth principles behind accreditation, however, the aim of the suggested programme is to provide specialist training within the context of a generalist outlook. Thus, the mix of courses selected seeks to provide the student with an integrated, yet modern view of the environmental engineering discipline, consistent with the economic and social realities faced by environmental engineers in the coming century.

It is envisioned that the following programme be covered in four undergraduate years, in line with the North American trend for engineering education. Each year consists of two semesters with a course being defined as the contiguous, standalone material taught during a semester (perhaps 14 weeks in length). The first year is specified such that it could be considered as a 'common year', suitable for all engineering students. This is an attractive option, not only for fiscal and administrative reasons, but also because it allows additional time for the student to mature before making a critical decision about his or her future career. The majority of courses in the early years would still need to follow a lecture-based format, primarily because of the need to transmit bulk information.

Table 2. Breakdown of core courses into fundamental units

Fundamental Unit	Title of Courses
Mathematics and Natural Sciences	Algebra and Vector Geometry
	Calculus I
	Physics for Engineers
	General Chemistry for Engineers
	Environmental Biology
	Probability and Statistics
	Calculus II
	Advanced Calculus
	Organic Chemistry and Biochemistry
	Differential Equations
General Engineering	Introduction to Computing in Engineering
	Engineering Economics
	Concepts of Mass Transfer and Materials Balance
	Introduction to Engineering Practice
	Fluid Mechanics
	Environmental Hydrology and Hydraulics
	Soil Mechanics and Geology for Environmental Engineers
	Hydrogeology and Environmental Geotechnology
	Numerical Methods in Engineering Analysis
Environmental Engineering	Technical Writing and Communication Skills
	Environmental Ethics
	Environmental Impact Assessment
	Environmental Policy and Law
	Systems Analysis
	Environmental Monitoring and Modelling Techniques
	Operations Research
Process Engineering and Pollution Prevention Sector	Thermodynamics
	Introduction to Biotechnology
Pollution Control and Treatment Sector	Water and Air Environmental Chemistry
	Water and Wastewater Quality Management
	Environmental Microbiology and Toxicology
Environmental Monitoring and Modelling Sector	Water Resources Systems and Planning
	Contaminant Transport Processes
Environmental Systems and Resources Management Sector	Ecological and Environmental Systems
	Environmental Resources Management
	Environmental Risk Assessment and Analysis

Table 3. Typical courses associated with different final-year sectors

Year Semester	Process Engineering and Pollution Prevention	Pollution Control and Treatment	Environmental Monitoring and Modelling	Environmental Systems & Resources Management
Year 4	Electrical Engineering	Biological Wastewater Trt.	Environmental Fluid Mech.	Limnology and Oceanography
1st Semester	Process Control Theory	Phys. Chem. Waste. Trt	Comp. Sim. in Environ. Eng.	Design of Ecolog. Syst.
	Sustainable Technologies	Environ. Samp. & Poll. Measure.	Finite Element Analysis	Aquat. & Terrest. Ecology
	Environ. Eng. Project	Environ. Eng. Project	Environ. Eng. Project	Environ. Eng. Project
	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective
	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective
	Environ. Eng. Practice	Environ. Eng. Practice	Environ. Eng. Practice	Environ. Eng. Practice
Year 4	Proc. Eng. Thermodynam.	Inst. Methods of Anal.	Water Res. Systems Model.	Environmental Toxicology
2nd	Instr. Control & Automat.	Eng. Design for Landfills	Water Quality Modelling	Population Ecology
Semester	Environ. Eng. Project	Environ. Eng. Project	Environ. Eng. Project	Environ. Eng. Project
	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective
	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective
	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective	Environ. Eng. Elective
	Environ. Eng. Practice	Environ. Eng. Practice	Environ. Eng. Practice	Environ. Eng. Practice
	Electives	Electives	Electives	Electives
	Noise & Vibration Control	Gas & Particulate Rem. Proc.	Micromet. & Atmos. Diffusion	Veget. & Wildlife Mgmt.
	Chemical Reaction Eng.	Hazardous Waste Trt.	Ocean Outfall Disposal	Conservation Biology
	Computer Control App.	Solid Waste Mgmt.	Remote Sens. Tech. & App.	Urban and Physical Planning
	Environ. Aud./Life Cyc. Anal.	Industrial Wastewater Trt.	Grdwat. Hyd. & Poll. Transp	Energy and the Environment
	Waste Minimization	Proc. Des. of WTP & STP	Air Qual. & Mgmt. Modelling	
			Environmental Geotechnology	

Where possible, however, each course should have a few weeks in which practising engineers are invited to give the students a flavour of the way information they have learned in class is incorporated into industrial and governmental practice.

Given the wide variety of courses possible in environmental engineering, it is prudent to specify a core number of courses common to all undergraduate students in the programme and from which they can branch out in their final year. Table 1 lists the core courses taken during the first three years. The courses evidence the commitment to a higher proportion than normal of the natural sciences, plus the environmental foundational skills outlined earlier, namely environmental ethics, communication skills, systems analysis and modelling. It is normal that an engineering undergraduate education encompass a certain percentage of the social sciences. While the curriculum does not directly provide an opportunity for the student to be exposed to these course as electives, it is maintained that the direct inclusion of some of the less rigorous engineering courses will breed the necessary social skills to function effectively in society.

In the final year, the students can specialize in one of four sectors. These sectors are broadly classed as follows:

1. Process engineering and pollution prevention sector
2. Pollution control and treatment sector
3. Environmental monitoring and modelling sector
4. Environmental Systems and Resources Management Sector

In order to enable the students to be adequately prepared to specialize in any of the four sectors, there is an interlinking of environmental components in the core years. Besides the foundational skills, every student will have been exposed to at least two or three courses which act as fundamental prerequisites for each of the sectors. Table 2 identifies the courses which would be labelled as lead-in courses enabling the students to specialize in any of the four sectors. Table 2 also breaks the remaining courses down into some fundamental background units of engineering.

The individual courses taken in each sector (Table 3) are in line with each sector's general theme. In the first semester of the final year, one of the environmental engineering electives would be from the chosen sector, while the other elective could be chosen from any of the remaining three sectors. Similarly, during the second semester of the final year, one of the electives would be from within the chosen sector, while the remaining two electives could be from any of the other sectors.

Finally, the programme does provide for a final-year design project which spans both semesters. The final-year project would be an individual effort in which the student worked on a single environmental problem under the guidance of a nominated faculty member or in conjunction with an individual from industry. The project would give the student the opportunity to produce a self-contained piece of design work as well as an excellent introduction to work in either industry or research.

CONCLUSIONS

Environmental engineering should be recognized as an engineering discipline in its own right. As such, environmental engineers should graduate from a distinctive undergraduate environmental educational programme that is not bound by accreditation requirements of other engineering degrees. This entails opening the curriculum to incorporate a broad variety of science-based courses, plus a widespread acceptance of what constitutes the foundational skills of environmental engineering. These courses should included environmental ethics, communication skills, systems analysis and modelling. A carefully crafted set of courses can result in a programme which is in keeping with the philosophical principles behind accreditation.

REFERENCES

1. M. A. Hashim, Environmental engineering education in Malaysia, *Proceedings of the Workshop on the Fundamentals of Environmental Education*, Christchurch, New Zealand (1994).
2. J. DuBose, J. D. Frost, J. L. A. Chameau and J. A. Vanegas, Sustainable development and technology, *Proceedings of the Workshop on the Fundamentals of Environmental Education*, Christchurch, New Zealand, (1994).
3. P. E. Vesiland, The future of environmental engineering, *ASCE J. Environ. Engng*, Editorial, **119**(4), 595–599 (1994).
4. C. N. Sawyer, P. L. McCarty and G. F. Parkin, *Chemistry for Environmental Engineering*, McGraw-Hill, New York, 4th edn, p. 658 (1993).
5. Z. Tadmoor, Engineering education in Israel 1992—in search of a new paradigm, *Int. J. Engng Ed.*, **9**(1), 71–75 (1993).
6. J. A. Manalo, Trends in environmental education—Philippine scenario, *Proceedings of the Symposium on Environmental Perspectives Towards the Year 2000 and Beyond*, AIT, Bangkok (1989).
7. World Commission on Environment and Development , *Our Common Future*, Oxford University Press, Oxford, p. 383 (1987).

8. M. M. Mena, The fundamentals of environmental engineering education, *Proceedings of the Workshop on the Fundamentals of Environmental Education*, Christchurch, New Zealand, (1994).
9. P. H. White, *Introduction to Engineering*, Wiley, New York, 2nd edn, p. 262 (1994).
10. G. Hauck, *The Aqueduct of Nemausus*, McFarland, Jefferson, NC, p. 210 (1988).
11. E. G. Garrison, *A History of Engineering and Technology: Artful Methods*, Boca Raton, FL, CRC Press, p. 276 (1991).
12. A. D. Cortese, Education for an environmentally sustainable future, *Environ. Sci. Technol.*, **26** (6), 1108–1114 (1992).
13. J. L. Craig, *Environmental Science, Technology and Engineering in Australia*, a report on visits to seven Australian universities, University of Auckland, New Zealand (1993).
14. G. Codner, D. Huisingh and M. S. Jorgensen, Environmental education for engineers, *UNEP Industry and Environment*, October–December (1993)
15. Institution of Civil Engineers, *Joint Board of Moderators: Explanatory Notes forModeration Visits*, p. 40. (1990)
16. D. G. Elms, The case of the missing foundation: systems thinking as a fundamental skill, *Proceedings of the 1993 Joint AEESEAP/FEISEAP/IACEE International Conference on Engineering Education*, (1993).
17. J. St J. S. Buckeridge, From reductionist to systems thinking: the engineering imperative, *Proceedings of the Workshop on the Fundamentals of Environmental Education*, Christchurch, New Zealand (1994).
18. D. G. Elms, Formation of the new engineer, *AEESEAP J. Engng Ed.*, **22** (2), 1–5, (1992).
19. N. C. Mickleborough and D. G. Wareham, Teaching engineering to increase motivation, *ASCE J. Professional Issues Engng Ed. Pract.*, **120** (1), 29–35 (1994).
20. H. T. Odum, Ecological engineering: the necessary use of ecological self-design, *ASCE J. Environ. Engng*, Editorial, **120** (3), 486–489 (1994).
21. P. N. Ramachandran, An innovative experience in environmental engineering education in India, *Proceedings of the Symposium on Environmental Perspectives Towards the Year 2000 and Beyond*, AIT, Bangkok, (1989).
22. D. A. Carlson and R. T. Skrinde, The environmental educational challenge: an opportunity for noble approaches to world problems, *Proceedings of the Symposium on Environmental Perspectives Towards the Year 2000 and Beyond*, AIT, Bangkok (1989).

David G. Wareham is currently a lecturer in the Department of Civil Engineering at the University of Canterbury, Christchurch, New Zealand. He received his B.A.Sc. and M.A.Sc. in civil engineering from the University of Waterloo, Canada and his Ph.D. in civil engineering from the University of British Columbia, Canada. Prior to his current position, he taught for three years at Asia's newest university—the Hong Kong University of Science and Technology. His research interests include automated control of wastewater treatment systems and optimization of biological nutrient facilities. Dr Wareham has worked and written reports for various governmental agencies in Canada, Australia and New Zealand, contributing mainly in the area of formulation of environmental monitoring systems and assessment of sewage treatment plant operating strategies.

Panagiotis Elefsiniotis is currently an assistant professor in environmental engineering at the University of Manitoba, Canada. He received his B.Eng. degree from the University of Athens, Greece and his M.A.Sc. degree in civil engineering from the University of Toronto, Canada. He then worked as an environmental engineer for five years in the private and public sector in Greece before pursuing a Ph.D. degree at the University of British Columbia, Canada. Following graduation, he worked for a year as a research associate with the newly established UBC Forest Products Waste Management chair. Dr Elefsiniotis teaches a variety of courses in environmental engineering and conducts research in the areas of biological nutrient removal and fermentation systems.