Teaching sustainable development to engineering students

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Abstract *Sustainable development is a complex concept which concerns a wide range of social, techno-economic and environmental issues. Without addressing all these dimensions, teaching of sustainable development would not be complete. Therefore, taught modules and teaching materials for engineering students should include not only technological analysis and economic evaluation, but also environmental and social considerations. This paper outlines the way in which a multidisciplinary approach to teaching sustainability has been embodied in learning programmes and activities in engineering at the University of Surrey, UK. More specifically, it describes a project to develop a comprehensive IT-based learning resource comprising a set of multidisciplinary case studies and support material in order to aid engineering students in understanding the concepts inherent in sustainability and how solutions can be developed.*

Introduction

Agenda 21, a global action plan for delivering sustainable development accepted at the Earth Summit in Rio de Janeiro in 1992, stated that "education is critical for promoting sustainable development and improving the capacity of the people to address sustainable development issues" (UNCED, 1992). The British government is a signatory of Agenda 21, and has since been actively involved in promoting sustainable development education. The "Toyne Report" of a Committee on Environmental Education in Further and Higher Education[1] appointed by the (then) Department for Education and the Welsh Office has made 27 recommendations for action that set an environmental agenda for further and higher education (DFE/Welsh Office, 1993). The Committee's recommendations for Further and Higher Education (FHE) Institutions ranged from formally adopting a comprehensive environmental policy statement and an action plan for its implementations, to "cross-curricular greening", i.e. developing the environmental understanding of students whose courses are not specifically "environmental" in focus. However, the 1996 appraisal of the progress which FHE institutions have made in the development of environmental education against the Toyne Report revealed "considerable indifference to the report's recommendations on the part of the

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institutions concerned" (Ali Khan, 1996). The 1996 Review of the Toyne report pointed out that the vast majority of FHE institutions have not yet developed environmental policies, and that hardly any progress has been made in respect of curriculum "greening" (Ali Khan, 1996).

In an attempt to encourage FHE institutions in the UK to introduce teaching of sustainable development into the curriculum, in February 1998 the Department of the Environment, Transport and Regions (DETR) established the Sustainable Education Panel. The aim of the Panel is to consider issues concerning education for sustainable development and to make practical recommendations for action. The Panel reports directly to the Deputy Prime Minister and the Secretary of State for Education and Employment, and lists as one of its objectives "to identify gaps and opportunities in the provision of sustainable development education and consider how to improve that provision" (DETR, 1999). In its First Annual Report (DETR, 1999), the Sustainable Development Education (SDE) Panel set a goal that by 2010 all further and higher education institutions should have staff fully trained and competent in sustainable development (SD) and should be providing all students with relevant SD learning opportunities. The Panel has also recommended that the Further and Higher Education Funding Councils should require institutions receiving grants to include SD in the curriculum and that all professional and industry-lead bodies should have SD education criteria included within their course accreditation requirements.

In the autumn of 1998, the UK-based organisation Forum for the Future conducted an audit of Higher Education (HE) engineering curricula as part of the Sustainability Development Education Panel's HE work programme. The survey was supported by the Royal Academy of Engineering and the Institutions of Chemical, Civil, Electrical and Mechanical Engineers. The objective of the curriculum audit was to assess the current status of SD education within higher education engineering schools or departments, and to take engineering educators' views on appropriate SD learning. The survey confirmed the findings of the 1996 Environmental Responsibility Review Report, and stated that "whilst a significant number of institutions have made an in-principle commitment to providing appropriate sustainable development education, hardly any have strategic programmes in place to implement their policy commitments" (Forum for the Future, 1998).

Informed by the findings of the engineering education survey and the comments of educators, the SDE Panel has developed a sustainable development education specification related to engineering education with the objective of developing and implementing SD education strategies. The Panel's research has suggested that sustainability concepts and solutions are two key areas of learning. The former include an understanding of the interdependence of natural, social and economic systems, the needs and rights of future generations and an appreciation for the need for precaution. Sustainability solutions are, among other issues, related to an understanding of the role of the engineering community in promoting SD, a sense of social responsibility and an awareness of tools and techniques for identifying more sustainable solutions. In the panel's position paper, the specification related to these areas is expressed in terms of learning outcomes which describe assessable changes in knowledge and skills development and behaviour that the engineering programmes, modules or learning materials should bring about. The Panel has also suggested that SD education is best integrated into specialist courses through learning activities which are firmly set in the context of the specialism, and that different learning activities and learning materials will be needed to deliver the sustainability learning agenda to students from the different branches of engineering (SDE Panel, 1999).

This paper outlines some of the ways in which the University of Surrey has responded to this growing public and professional interest in SD education. More specifically, it describes our way of teaching SD to undergraduate and postgraduate engineering students, which in many respects corresponds to the sustainability learning agenda set out in the position paper by the SDE Panel.

University of Surrey

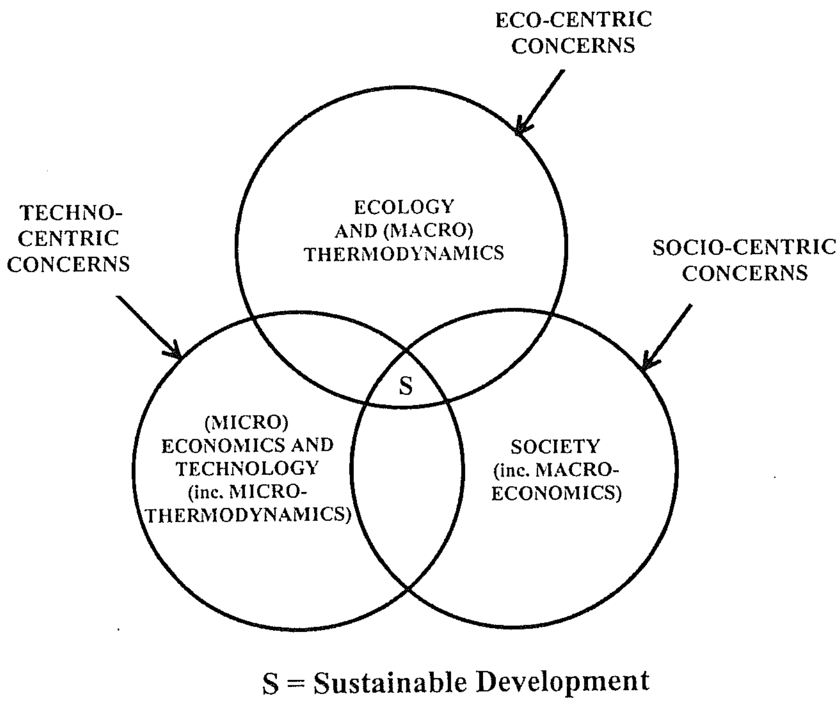
The University of Surrey (UniS) was established in 1966 but its roots go back to a late nineteenth century concern to provide greater access to further and higher education for the "poorer inhabitants" of London. The forerunner of the University, The Battersea Polytechnic Institute (founded 1891, first students admitted 1894) began concentrating on science and technology from about 1920; its graduates were awarded degrees of London University. Its academic reputation steadily grew to the point in 1956 where it was one of the first colleges to be designated a "college of advanced technology", when it was renamed Battersea College of Technology. By the beginning of the 1960s the College decided to move to Guildford. In 1966, Battersea College expanded and became the University of Surrey, awarding its own degrees.

Since its foundation, UniS has become one of the UK's leading professional, scientific and technological universities with a world class research profile and a reputation for excellence in teaching and learning. UniS enjoys a reputation for its research work in the areas of health, medicine, space science, engineering, the environment, communications, defence and social policy. In February 1997 it was awarded the Queen's Anniversary Prize for Higher and Further Education. Now over 30 years old, UniS has 2,500 staff, and some 9,100 full-time students and a further 12,000 students undertaking Continuing Professional Development programmes provided by the university. The academic disciplines are arranged in schools covering the areas of engineering, science (including health sciences), human sciences, management studies, languages and performing arts. The vocational ethos, inherited from Battersea, has been sustained: programmes at both undergraduate and postgraduate levels have a strong emphasis on enabling students to develop their academic specialisms and gain professional and personal skills which will enhance their career prospects.

UniS accepts its environmental responsibilities and recognises its obligations to contribute to the resolution of global and local environmental issues by reducing its environmental impacts and by taking a leading role in promoting environmental good practice. In its Environmental Policy Statement, UniS expresses commitments to seek to ensure that all academic programmes help students to develop their environmental awareness and understanding, and encourage and facilitate research on environmental sustainability (UniS, 1999). These commitments are demonstrated through the introduction of suitable policies, practices and programmes.

Sustainability teaching programmes at Surrey

SD is a complex concept which concerns a wide range of social, techno-economic and environmental issues. Adopting this idea, the SD education programmes for engineers at Surrey are based on belief that SD engineering education is about giving engineers an understanding of the issues involved as well as about raising their awareness of how to work and act sustainably. The resulting concept is that the engineer should be a technical expert who acts as a social agent, rather than just a technician (Clift, 1998). This is summed up by Figure 1. Conventional engineering education is limited to techno-economic issues; for example, micro-economic assessment (such as net present value) is usually presented as the basis for engineering decisions. However, sustainable



Source: Clift (1998)

Figure 1.
Sustainable development as the intersection of three sets of priorities and constructs

development embraces environmental and economic performance, and also social aspirations and constraints. Sustainable development is therefore represented by the overlap region at the centre of Figure 1.

Without addressing all of these dimensions of SD, teaching sustainability would not be complete. Therefore, the modules and materials for teaching sustainability to engineering students must include not only technological analysis and economic evaluation, but also environmental and social considerations. This multidisciplinary approach has already been embodied in our teaching programmes, and we consider it to be essential.

A number of post-graduate programmes have been developed at Surrey which incorporate the multidisciplinary approach to teaching SD. Perhaps the most conspicuous of these has been the Engineering Doctorate (EngD) in Environmental Technology. A feature of the EngD programme is that all students (research engineers) are sponsored by companies and organisations external to the university. The research engineers spend about three quarters of their four-year studies at the sponsoring companies; the rest of the time is taken up by intensive one-week taught modules at the university. The premise for the programme is that the environmental managers who will "make a difference" in future will need to be first-rate engineers and applied scientists, but will also be required to have a broad understanding of the social and philosophical context in which they will work. Thus, the course modules cover a wide range of subjects from clean technology and risk management to sociology of the environment and environmental ethics. The skills and knowledge acquired in the taught component of the course are then implemented in the project work carried out with the industrial sponsor. The final output of their work is a portfolio of projects which have a common thread related to sustainable concepts and solutions. Thus, compared to a conventional PhD degree, the EngD programme has an additional value: it trains students to work on sustainable development issues in an academically rigorous manner but in an industrial environment.

Another postgraduate programme, the MSc in Environmental Strategy, also embodies this ethos. The programme provides a firm theoretical and practical grounding for evaluating technical, social and economic aspects of environmental problems, and knowledge of the various analytical tools and methods available to help the problem-solving process. Throughout this programme, emphasis is placed on the multidisciplinary approach to decision-making by drawing from the pool of expertise at Surrey, ranging from engineering and science to sociology and philosophy.

The developments at the postgraduate level have recently been extended and incorporated into undergraduate engineering programmes. As a result, we are developing multidisciplinary teaching materials related to SD for use in new undergraduate programmes in engineering. Although some teaching of SD issues at undergraduate level have existed since early 1996, particularly in Chemical Engineering degree programmes, this material has evolved over the years and is now being broadened and consolidated. The core of the programme will be sustainable development and engineering. There will be a family of MEng and BEng degrees following either chemical, civil or mechanical and materials engineering.

Although strongly grounded in an engineering discipline, the emphasis of these programmes is on sustainable development, the problems that are created by human activities and on the contribution of the engineer to solving them. The intention is to educate the new type of engineer (Clift, 1998), who will not only be capable of designing and operating facilities to produce products and manage wastes, but who will also be able to go beyond waste management and re-engineer processes to reduce or avoid generation of waste. They will be able to understand the technical, economic and social influences which drive the way in which goods and services are provided, which help or limit recovery and recycling of used products, and which limit the take-up of clean technologies. Graduates from these programmes will also be given the necessary grounding in environmental science, and combine this with technological understanding, so as to develop and design new ways of meeting human needs which impact less on the environment. So, while still being engineers by profession, graduates from these programmes will have an additional dimension in that they will also be able to understand and solve environmental and social problems associated with industrial activities.

The programmes have the same core element related to SD which occupies about one quarter of each programme. The remaining three quarters are related to the respective engineering discipline, i.e. chemical, civil or mechanical and materials. The SD subjects are introduced gradually from level one and are broadened in scope and complexity as appropriate for the higher levels of study. Experience with our students on Chemical Engineering programmes, for instance, suggests that students leaving school have very little or no understanding of basic environmental issues and problems, and only few of them have heard of SD (Azapagic, 1996-1999). Therefore, the new programmes have been designed so as to introduce students to the concepts of SD and major environmental issues very early on in their study, i.e. at level 1 (see Figure 2). We also practice this with our existing Chemical Engineering courses at level 1. In addition, students of Engineering for the Environment learn about eco-systems and pollution at level 1. At level 2 they study different environmental strategies and management practices that exist or can be developed for more sustainable industrial systems. This continues at level 3 with various tools and approaches, such as life cycle assessment, waste minimisation and pollution prevention.

A further module on SD pulls together all three dimensions of sustainability in Figure 1 and encourages students to find sustainable solutions in various case studies through workshops, project work and written essays. The BEng students graduate at this level while the MEng students continue for one further year. The final MEng year is designed to broaden the knowledge and understanding of SD issues and includes a number of optional modules such as environmental law; environmental risk; values, ethics and the environment;

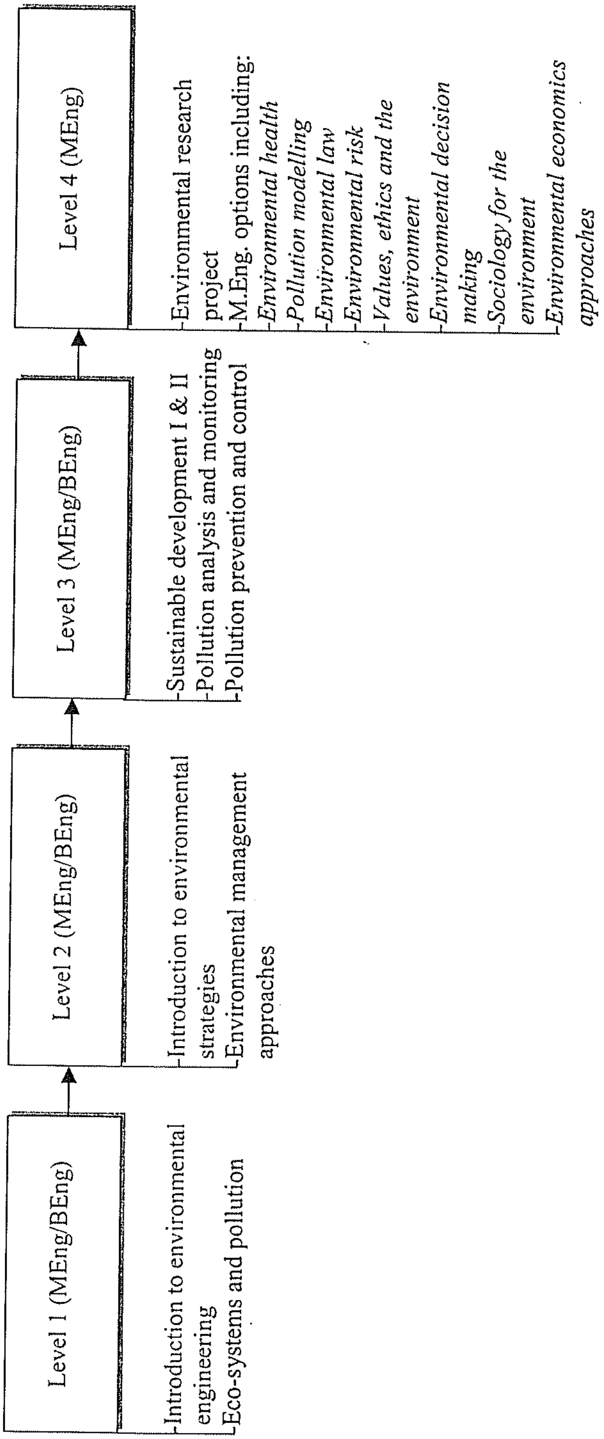


Figure 2.
A part of the Engineering for the Environment curriculum related to sustainable development

sociology for the environment; and environmental economics approaches (Figure 2). At this level students also carry out a multidisciplinary design project where all engineering disciplines work together to design a plant or a facility taking into account the principles of SD. The latter is currently practised on our existing conventional engineering courses across the university and students find it an excellent experience. Our Chemical Engineering for the environment programme has just been fully accredited by the Institution of Chemical Engineers (I.Chem.E.) who are also becoming aware of the importance of SD and seeking ways to promote teaching of sustainability to engineering students.

As a part of these developments, we are also exploring the ways in which we could use more advanced teaching methods to introduce SD to our undergraduates. This approach is explained in the next section.

Developing innovative learning materials

Although limited learning material for SD is already available, more work is needed to develop, organise and consolidate case studies, findings of completed or ongoing projects, and course notes into an all-inclusive teaching and learning resource. The authors of this paper are involved in a project to develop a comprehensive IT-based learning resource (a multimedia learning package) comprising a set of multidisciplinary case studies and support material in order to aid engineering students in understanding the concepts and solutions of SD. The IT-based learning resource is being developed to cover the following elements:

(1) introduction to sustainability concepts; and

(2) case studies and sustainable solutions.

Introduction to Sustainability Concepts[2] includes the following areas:

- an understanding of the interdependence of major systems;
- an understanding of the needs and rights of future generations;
- an understanding of the value of diversity;
- an appreciation for the need for precaution; and
- an awareness of the Earth's "carrying capacity".

The support material specific to case studies covers:

- technical specification of problem;
- "worked examples" of possible solutions; and
- identification of environmental, social and economic issues involved.

The project is supported from two sources: the University of Surrey's Strategic Fund for Teaching and a grant from the Royal Academy for a Visiting Professor in Engineering Design for Sustainable Development. The latter is specifically aimed at developing case studies related to SD to be used in existing and new undergraduate programmes in engineering, with the objective of disseminating best practice to other universities in the UK.

The project draws on current research and teaching material in engineering at Surrey. The "Introduction to Sustainability Concepts" incorporates a multimedia course on environmental ethics already developed at Surrey (see below). In our existing programmes, environmental ethics is taught at the postgraduate level. A module on Values, Ethics and the Environment is one of the core modules of the MSc in Environmental Strategy, and is also incorporated in modules in the Engineering Doctorate Programme. Environmental ethics is also taught as a short Continuing Professional Development (CPD) course aimed at planners and policy makers, environmental managers, corporate and public affairs managers, environmental consultants, etc. The modules on environmental ethics explore the different value approaches and ethical principles underpinning sustainability, and cover subjects such as environmental values, intergenerational and intragenerational equity, and relevant ethical issues raised by climate change, the loss of biodiversity, genetic engineering and so on.

These subjects are taught by a multidisciplinary team of expert lecturers and practitioners that includes philosophers, sociologists, engineers, and environmental managers. The modules are structured to combine both lecture sessions and facilitated small-group discussions on specific topics. Case studies and role-plays are used to explore and debate different approaches. The objective is to enable engineering students to clarify the principles and values on which environmental decisions are made, and help them in developing an ethical framework to address environmental issues as they arise.

In order to support existing teaching of the subject, and to consolidate various course notes, interdisciplinary data and audio-visual materials, one of the authors (SP) has developed an IT-based learning package on environmental ethics. Using text, sound, interactive exercises, and video, the learning package gives an introduction to environmental ethics, and examines discussions of environmental responsibility. It gives the scientific background necessary to understand complex environmental issues, and building on this factual base, it explores some important ethical issues raised by environmental problems. Different ethical approaches to the environment are presented in a balanced and impartial manner. While refraining from promoting any particular viewpoint, the learning material is designed to encourage students to actively analyse and evaluate different ethical perspectives. This learning package is currently being expanded to cover other elements specified in the "Introduction to Sustainability Concepts" to be delivered to engineering students at the undergraduate level.

The case study material draws from several "internal" and "external" sources. Perhaps the most distinct among them are the graduating portfolios from the EngD programme; work on applying life cycle assessment to chemical and mineral processing (e.g. Azapagic, 1999; Azapagic and Clift, 1999); work on waste management carried out for the Environment Agency and DoE (Environment Agency, 1997; Clift 1999; Clift *et al.*, 2000), and a major LINK project on a decision-support framework for plastics recovery, recycling and re-use (Stevens *et al.*, 1997-2000). One of the features of these projects is the inclusion into engineering design decisions of criteria which do not derive solely from technical and micro-economic considerations, but include wider socio-economic and political issues.

Drawing on the expertise available at Surrey, these new approaches to decision structuring and analysis are included in the case studies. External sources, such as the case studies published by the World Business Council for Sustainable Development (WBCSD, 2000), and the United Nations Environment Programme will also be consulted and included as appropriate. The case studies cover the following areas:

- chemical/mineral processing;
- recovery/recycling/re-use; and
- dematerialisation.

The case studies in chemical/mineral processing focus on selection, design and operation to minimise total resource use and environmental impacts integrated over the whole life cycles of materials and energy (Azapagic, 1999). Specific cases include:

- operation of a mine and processing facility producing different boron products;
- alternative approaches to NO_x abatement and suppression in industrial processes; and
- use of oxygen as an alternative to air in oxidation and waste treatment processes.

These examples are at the more conventional engineering end of the spectrum. However, they go beyond conventional engineering approaches in considering life cycles, and in introducing the important principle that SD requires decisions based on a number of disparate criteria or objectives – in these cases, economic performance plus a number of incommensurable measures of environmental impact and resource use.

The case studies in recovery/recycling/re-use cover design, planning and operation of processes, ranging from management of the life cycles of specific materials (such as metals and plastics) through to integrated management of waste water and mixed wastes (including Municipal Solid Waste). Specific cases include:

- managing the "industrial ecology" of steel and aluminium;
- designing local schemes for recovery and beneficial use of low-density wastes such as paper and plastics;

- designing life cycles (and the necessary infrastructure) for multiple use of plastics;
- identifying sustainable strategies for managing water and waste water at both industrial and municipal levels.

The shift from selling products, through leasing products, to providing a service, known as dematerialisation, is another area covered by the case studies which include:

- photocopiers and de-greasing solvents, as examples where the shift to service provision can be complete;
- the implications of "take-back" legislation, under which the supplier retains responsibility for the material product (as enforced by various EU Directives on End-of-Life of products);
- energy service contracts, which provide specified conditions (e.g. temperature in offices and homes) rather than charging for energy use.

Following recommendations by the Royal Academy of Engineering (McQuaid, 2000), the case studies will be real rather than theoretical with emphasis on principles rather than detail. Students will have to examine a range of possible options and will have to evaluate the trade-offs to make "right" decisions. Each case study will have a multidisciplinary approach which will combine engineering, economic, social and ethical elements. Engineering students will also have to learn how to cope with inadequate information and uncertainty requiring construction of scenarios, making assumptions, performing sensitivity analysis and exercising judgement. The first case studies will be developed and implemented in September 2000 with the others developing in parallel. It is expected that the full package will be available sometime by 2003. Because the case studies are not intended to be linked closely to any one branch of engineering and because they are intended to provide a continuous development towards the broad approach needed to address SD, it will in principle be possible to use them in all engineering programmes. After "track-testing", it is hoped that the learning package with the case studies would be taken up in other engineering programmes, both at Surrey and elsewhere.

Thus, the case studies in these areas will illustrate how publicly acceptable quality of life can be delivered economically but with greatly reduced resource use and emissions. The application of leading-edge concepts and approaches to SD in the case study material, and particularly the introduction of problems which have social, environmental and ethical dimensions into engineering learning activities and learning materials, represents a distinctively novel quality in engineering education programmes. Furthermore, the translation of the conventional educational material (i.e. the case studies and support material) into an IT-based interactive learning package provides a more convenient and efficient access to a large body of interdisciplinary data and audio-visual materials, thereby offering an effective and innovative means to deliver the sustainability learning agenda.

Conclusions

Currently, engineering programmes at the University of Surrey are being reviewed and changed to incorporate recent developments in engineering disciplines and advances in teaching. As a part of this initiative, new modules that underpin the concepts of SD are being developed, while some of the existing modules are being adapted to reflect its philosophy. Furthermore, new programmes are also being developed, which will pull together the wealth of experience in SD teaching at Surrey. The aim of the project on "Teaching Sustainable Development to Engineering Students" described in this paper is to facilitate these initiatives, and to contribute to a more effective sustainability teaching, creating a rich and varied learning environment for the students.

Finally, the project reinforces the environmental policy of the University of Surrey by helping students to develop environmental awareness and understanding of sustainability. We believe that our programmes, modules, learning activities and materials as described in this paper correspond to the engineering specification for sustainable development education recommended by the Sustainable Development Education Panel, and contribute effectively to achieving the common aim, i.e. "to enable people to develop knowledge, values, and skills to participate in decisions about the way we do things individually and collectively, both locally and globally, that will improve the quality of life now without damaging the planet for the future" (SDE Panel, 1999).

Notes

1. The Committee on Environmental Education in Further and Higher Education was appointed to make an assessment of what needed to be done "to provide the workforce with the knowledge, skills and awareness which it will need to assume greater environmental responsibility". In 1993 the Committee published a report which is referred to as the Toyne report, after the committee's chairman, Professor Peter Toyne.
2. As reported in the Sustainable Development Education Panel's position paper, Forum for the Future/DETR, February 1999.

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