DEVELOPING SUSTAINABLE PRODUCT DESIGNS USING A CASE STUDY AND PROJECT APPROACH

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ABSTRACT

Today's design emphasis is being driven by sustainability, inclusivity and end of life cycle with a renewed interest in green issues where recycling should now replace the throwaway culture.

It is now demanded that products are designed to be reliable, readily recycled, compostable or easily biodegradable. Packaging of the product also has to be considered.

To meet these requirements students on the BSc (Hons) Product Design and Innovation degree course at the University of Wolverhampton are encouraged to consider the design of the life cycle of the product in addition to the design of the product itself. Sustainable product design is introduced in modules through lectures and seminars using case studies and projects to introduce the theory. Students are also introduced to existing products and asked to re-evaluate the design to consider sustainability aspects.

The students are expected to undertake research into these particular areas for their product design and then communicate their final designs through presentations, design competitions and formative peer group assessment.

This paper discusses how sustainability is embedded through the use of case studies and a final year project to undergraduate students on the BSc (Hons) Product Design and Innovation course.

INTRODUCTION

One of the recommendations of the Department of the Environment(1) is that by 2010 all professional and industrial lead bodies should have sustainable development criteria included within their course accreditation requirements.

The BSc (Hons) Product Design and Innovation three-year full-time course at the University of Wolverhampton has evolved, since 1989, to reflect current and emerging methodologies in product design.

The International Conference on Engineering Education(2) recommended that higher education is essential if sustainable development and therefore, social progress is to be achieved.

SUSTAINABILITY ISSUES IN PRODUCT DESIGN AND INNOVATION

Since the mid 1990's the course team have engaged in sustainability issues to inform the course curriculum. Sustainability issues are now an integral part of the curriculum for this award where product design and innovation are used as tools to investigate existing and new products.

Drahun *et al*(3), suggest that to support the continuing advance of the concept it is essential to convey the sustainability message through future generations through the education system.

Our sustainability curriculum concentrates on the three main areas of sustainability referred to in the Design Council(4):

- Social – people
- Environmental – planet
- Economic – profit

These are introduced as concepts in the first year of the course and then developed with lectures, seminars, individual and group presentations in years two and three.

In years two and three of the award students are expected to undertake research to demonstrate their awareness of sustainability issues for their products.

A cradle-to-cradle life cycle approach is taught where students are encouraged to identify that the end of one product life cycle is the beginning of another. By adopting this methodology products are designed to be reused, remanufactured or recycled as stated by Papanek(5) in his chapter ‘Designing for a Safer Future’.

THE ROLE OF CASE STUDIES AND A PROJECT

Year 1

The first year of the course is a diagnostic year, where students are introduced to the three principal concepts of sustainability. In the first year module ‘Fundamentals of Computer Aided Design 1’ the students were given a ‘design and make’ assessment task of designing and building a portable chair that could be used for outdoor concerts. The students were required to work in groups of two and the material that they had to use was recyclable cardboard, which had been obtained from packaging cases.

The aim is that people attending outdoor summer concerts would be issued with a flat pack of cardboard, which they would assemble into a seat at their chosen seating area within the grounds of the concert.

Students and concert attendees would be aware of the following:

Social - they all have the same recyclable cardboard seats.

Environmental - once the concert has finished the attendees could take their chairs home and re-use them time and time again.

Economic - the cost of the chairs has been minimised.

Figure 1 shows two group solutions to this task.

Students, as part of their group assessment had to present their solution to their peers and academic staff and prove that their flat pack solution could be assembled into a fully operational chair and then disassembled into a flat pack.

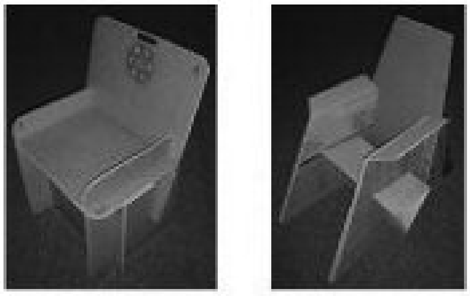

Figure 1: Cardboard chairs, year 1

Year 2

In the second year module ‘Design Practice’ the students were given a ‘design and make’ assessment task of designing and building a portable multi-purpose exercise bench that could be used for two different types of exercises. The students had to produce a product that could be used for both step aerobics and non-aerobic exercises; sit-ups, crunches and squat thrusts.

The students were required to work in groups of two and the material that they had to use was recycled steel. The portable exercise bench could be used indoors, outdoors and could also be transported in the boot of a car so that users could, for example, take it with them on short trips and holidays.

Users of the product would be aware of the following:

Social – the exercise bench is multi-functional and portable.

Environmental - once the user has finished their exercises they could take the exercise bench home and re-use it.

Economic - the cost of the bench has been minimised, since recycled steel has been used in its manufacture.

Figure 2 shows a group solution to this task.

Students, as part of their group assessment had to present their solution to their peers and academic staff and prove that their exercise bench could be assembled, used for aerobic and non-aerobic exercises, disassembled and fitted into the boot of a car.

Figure 2: Exercise bench, year 2

Year 3

In year 3, the final year, two modules; ‘Design Competition’ and ‘Project’ are specifically designed to allow students to consider sustainability issues.

Design Competition Module

The title of the product brief for the academic year 2003-2004 was ‘Sustainable Design’ and was based around a national design competition. The design brief required the students to select and appraise an object and redesign it to:

i) Achieve a decrease in the environmental impact from the creation, use and disposal of the product
ii) Achieve an increase in the business potential of the product

Figure 3 shows the solution to this brief entitled the Eco-Block, which is a revolutionary sustainable building block.

The Eco-Block is a natural lightweight building block that could be used in the construction of internal walls. It has the strength of a concrete block but is lighter and can be laid with glue instead of mortar. Its thickness is 100mm and conforms to mandatory requirements of sound and thermal insulation.

The block is revolutionary in its design because of the choice of material; it is manufactured from miscanthus fibres blended with natural resins with fire retardant and water resistant additives to make it durable.

Miscanthus is a renewable energy crop that specialises in the reduction of greenhouse gases by extracting carbon dioxide from the atmosphere and is both economically and environmentally sustainable.

Benefits of the Eco-Block

- It is easier to lay because it is lightweight.
- Productivity will increase.
- Transportation costs will be lower.
- Blocks will be easier to move on-site.
- Energy savings.
- Environmentally friendly.
- Miscanthus specialises in extracting carbon dioxide from the air.

Market

The intended market for the Eco-Block is the housing, construction and industrial sector. The block is suitable for all internal walls, however in drier countries it could be used for outside walls.

Existing Product

The new Eco-Block will compete with concrete blocks in the construction of internal and, where appropriate, external walls. It is a substitute for the non-environmentally friendly concrete blocks presently available.

The Eco-Block is also compatible with existing 100mm blocks.

There is no concrete or cement in the natural Eco-Block and there is no need for mortar – the blocks are glued together.

The new Eco-Block is easier to work with than concrete blocks.

Block Properties:

70% miscanthus fibres
25% natural resins
5% fire retardant and water resistant additives

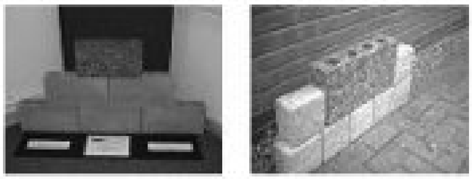

Figure 3: Miscanthus block by Simon Middleton, year 3

Estimated Costing:

Miscanthus fibres	£40.00 per tonne
Resins	£6.00 per kg
Fibres	£0.35 per block
Additives	£0.15 per block
Resins	£0.20 per block
Manufacturing	£0.45 per block

Estimated price = £1.15 per block

Project Module

Figure 4 shows a product area within the field of medicine that has not been utilised to its full potential is the field of inhalers – the area that has potential for further investigation is the area of dosage measurement.

The Original Design of Inhalers

Probably the most familiar form of inhaler is the aerosol inhaler. This simply consists of a removable aerosol canister and a simple casing that includes the mouthpiece. The main drawback with this particular product is that, with canisters that contain up to 200 dosages a simple monitoring sequence for tracking the quantity within the canister is simply not viable. This is due to the fact that these canisters, depending upon the dosage set by the patient's doctor, can last up to eight weeks. Some patients have to use more than one type of aerosol inhaler, therefore monitoring becomes an extensive daily task resulting in unknown dosages left within the canister.

This excessive quantity of inhalers in circulation costs the National Health Service millions of pounds per year.

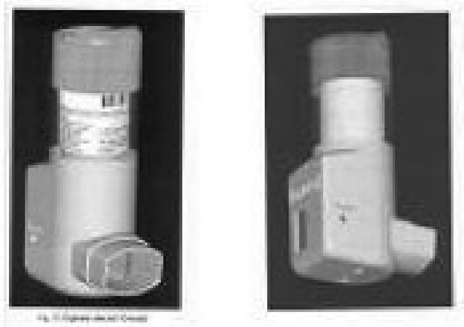

Figure 4: Digital aerosol inhaler by Chris Turton, year 3

Proposed Design Solution

The product in **figure 4** solves the problem by introducing a liquid crystal display, which would be used to count dosages within the canister. This could save considerable amounts of money for the National Health Service because it will remove the requirement to have more than one inhaler per person.

The student designed a questionnaire, which was circulated to patients and the results highlighted problems and possible solutions.

Not one aerosol inhaler on the market included a counter to monitor dosages and the concept of one such inhaler was well received by the doctors that were consulted in its evaluation.

The questionnaire results highlighted that only 33% of users knew that an unnecessary £20.00 per person was being wasted. The excess costs for the people owning six to eight inhalers ranged from £50.00 to £70.00.

The questionnaire results showed that 57% of the people asked disposed of their inhaler before it had its full use. Once again this reverts back to the issue of money wasting. If the canisters were being used completely this would reduce the cost of replacements because they would not have to be issued so regularly.

Design Specification

The inhaler design specification required a counting device that would count each operation of the inhaler and also be able to accept all aerosol canisters available on the market. Furthermore, the design should be manufactured from materials that would not only maintain structural integrity but also remain comfortable for the user.

Conditions in Use

The product should be able to be operated easily with one hand and the materials selected must be corrosion resistant and lightweight for ease of use.

The inhaler must also be robust enough to avoid any leakage or misdirection of spray.

Design Characteristics

The body of the inhaler should be a different colour from those allocated to drug types.

The ergonomics should provide comfort and ease of use during operation and the inhaler should be lightweight so that it can be carried comfortably.

No part of the inhaler or counting device should interfere with the operation of the canister or direction of the canister discharge.

The inhaler should be able to be dismantled for servicing or installation of canister and the counting device must be able to be reset when a new canister is installed.

Reliability

The inhaler, including the counting device, should be able to last for a minimum of one canister disposal.

At no point should the inhaler lose count of the dosages taken from a canister during the canister's life.

Servicing Features

The inhaler must allow for renewal of the aerosol canister and the counting device must be accessible for service during a canister change.

Display Counter Considerations

The solution utilises a liquid crystal display electronic counter, with micro-switches. The power supply would be approximately 1.5 volts, similar to that of a watch. A simple micro-switch would be used for the reset. The casing of the inhaler would be moulded as a single unit with fittings moulded in to accept the electronic components.

The advantages are:

1. Using a liquid crystal display would supply clear figures for the dosage counts.
2. The small size of modem electronic components means that they could be positioned in numerous places.
3. It has the potential of a very long battery life due to low power drains.

The cost of the electrical components would be approximately £15.00 for a single prototype. This would reduce considerably if the design went into mass production with a new liquid crystal display being utilised. The proposal includes new ideas and technologies, introducing a new aspect to the inhalers being used. Therefore, these modifications ensure that the proposal is feasible and should be continued through the design process.

CONCLUSION

The authors believe sustainable and conservation issues need to be high on the design agenda for the education of tomorrow's product designers who will be responsible for the design of a new generation of sustainable products.

In order to help prevent household and consumer waste spiralling out of control it is required need to effect a paradigm shift in thinking among tomorrow's product designers, who not only need to design products but product life cycles from cradle-to-cradle rather than cradle-to-grave.

Many new products are developed using the established practices of design for assembly and design for manufacture. However, design for disassembly needs to taken into account and a culture amongst product designers of design for longevity, repairability and recyclability needs to be established.

The goal is to design products that satisfy the customer and minimise environmental impact over the product's life cycle. This is often referred to as sustainable design or cleaner product design, thus trying to alleviate the many products that often end up in landfill.

Felton and Bird(6) recommend that the following key points should be considered to reduce a product's environmental impact through:

1. Reduced raw material
2. Reduced use of energy
3. Less pollution and waste
4. Elimination of hazardous materials
5. Increased service life
6. Greater potential for recycling

To support the continuing advance of sustainability it is essential to convey it to future generations through our education system.

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REALISTIC STUDENT ENQUIRIES AND CAPACITY BUILDING FOR ENGINEERING SOLUTIONS TO WORLD POVERTY

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INTRODUCTION

Consider the expertise and creative talent present within universities, as well as their extensive facilities and economic resources. Where engineering is concerned, universities have the wherewithal to help develop capacity for low-cost sustainable solutions to a range of real-world problems, promoting solutions to global poverty. By contrast many indigenous communities lack local capacity for engineering. As yet such potential with universities remains relatively untapped globally; it is therefore important to explore possible approaches, such as the partnership initiated during 2001 between the charity Developing Technologies and Imperial College London, which now jointly provides a student-based engineering design service for development organisations.

The partnership relies on engineering solutions that involve appropriate technology – and thus technological solutions that can be designed, made and tested by engineering students themselves, as well as sustained in local communities. This focus on student work lends itself to education built around realistic student enquiries, linking also to project-based learning or capstone courses (Dutson *et al*[1]), problem-based learning (Bound and Feletti[2]), and enquiry or inquiry based learning more broadly (Savin-Baden[3]).

This study outlines an evaluation of the effectiveness of the partnership between Developing Technologies, Imperial College London and the development professionals, looking at its role in educating students for development work, and thereby considering a number of issues related to enquiry-based learning that have received relatively little attention, leading also to strategies that might help to manage the issues that are raised.

THE FRAMEWORK FOR THE EVALUATION

The methodology underpinning this evaluation is one that is both accessible and systematic – drawing on the Walker model (Valdez[4]). The evaluation begins with a statement of the purpose of evaluation, which in this case was to explore the extent to which the partnership has been effective in educating the students to provide engineering solutions to world poverty. However, the use of realistic student enquiries as a means to this end also provides an important focus – given that this was the educational approach adopted by the partnership. These purposes then lead us to frame the primary objectives for the evaluation, building on objectives outlined in Developing Technologies(5): to what extent has the partnership been successful in educating students as professional engineers, through realistic enquiries linked to the developing world; and, to a lesser extent, in building capacity for engineering solutions for the developing world?

The evaluation further incorporates a model of change, which here lies in the use of realistic enquiries, carried out by students with appropriate patterns of support. Edelson(6) notes in this support the role of student motivation, accessibility of the tasks, level of background knowledge, ability to manage an enquiry and resource constraints. Enquiry-based learning represents a shift away from more passive methods involving the transmission of knowledge to students to active approaches in which students are expected to direct and research their own lines of enquiry, as Kahn and O'Rourke(7) argue, contrasting with some project work in which students follow a course laid down by the tutor.

Indicators then provide a framework for identifying data sources, designing data collection methods and analysing the data; the

	Outcomes	Process	Enabling
Design, make, test	Ability to design, make and test; related self efficacy; awareness of strategies to improve ability	Conduct of the design, manufacturing and test stages of the project	Facilities, resources and technical assistance; contributions from client, professional adviser and supervisor; motivation stemming from realistic nature of project
Team work	Team-working skills; self efficacy in relation to team-work; awareness improvement strategies	Conduct of the group process	Facilitation by supervisor; basis on which groups are established
Project management	Project management skills; self-efficacy in relation to project work; awareness of strategies to improve project work.	Management of the project	Appreciation for difficulties inherent within design, manufacture and testing; clarity of initial project specification
Capacity for developing world	Ability to tailor engineering solutions for developing world; awareness of how to develop this ability; willingness to engage in development work	Gaining an understanding of the specific area of engineering and client requirements; management of client relationship	Availability of information on the technology and client requirements; arrangements for communication with client; motivation stemming from development context

Table 1: Indicators for the evaluation, with a focus on student learning

remaining steps in this approach to evaluation. We classify in **table 1** the indicators under three categories: outcome, process and enabling, on the basis of Helsby and Saunders' EPO methodology(8). Enabling indicators concern those dimensions that need to be in place for members of the project team to work successfully. Process indicators refer to actions that team members carry out during the project, while outcome indicators concern with the end points of the project, particularly the resulting student learning. It is useful to draw on the categories developed by Knight and Yorke(9): understanding; skills; efficacy beliefs (which concern the willingness of students to persist with complex activity); meta-cognition (or the awareness of, and control over, cognition). The final selection of indicators was made in the light of an initial analysis of the data.

Data to address these indicators particularly concerns the student experience, given the focus on their learning. In the period covered by this evaluation (2001-2004) 51 students on undergraduate degrees within the Department of Mechanical Engineering at Imperial College London carried out a project with support from Developing Technologies; of these, working in 10 separate teams, 43 carried out a 'Design, make, test' (DMT) project within their third year. Each project involves students designing, making and testing a solution to an engineering problem. For instance, projects included developing a grass mower for rural Romania, a laminar flow cabinet for the cultivation of seedlings in Zimbabwe and a micro-hydraulic turbine generator for the developing world. Thirty two of these students were involved in what were termed partnership projects, where the students also dealt directly with a client in a developing country, as in the projects for Romania and Zimbabwe. The assessment of the project work includes a report on the project by the team of students, incorporating a personal critique of their project by each student, typically around 500 words in length. While the students may exercise care in criticizing any support that they receive, the critiques provide a detailed source of naturally occurring qualitative data. Measurement against the indicators largely occurs on the basis of this qualitative data; we thus rely on the Mode 1 concept of indicators as a focus for data collection and analysis, as outlined by Saunders(10). It was decided to supplement these critiques with a brief questionnaire to provide further qualitative data on the student viewpoint, including such questions as 'How have you benefited from participating in a Developing Technologies project?' and 'What challenges have you faced?'

REPORTING AGAINST THE INDICATORS

Overall, 550 comments from the critiques were categorized against the indicators in **table 1**. Given the limitations of space within this paper, after brief overviews we concentrate our reporting on issues of particular interest that have emerged from the analysis against the indicators.

Issues related to designing, making and testing

Technical issues involved in the projects dominated the concern of students (213 comments). In terms of process, the projects appear not surprisingly from the student view point to have been successful, with 40 students claiming technical success given the circumstances that they had faced, although concerns were raised by 14 students over the heavy workload on the project (e.g. 'The workload was exceptionally high when compared to other groups'). With regard to enabling factors, effective support from supervisors, technicians, external professionals within the UK external to the College, and local partners overseas was noted in 23 comments, with inadequate support only noted on the 3 occasions (e.g. 'We ended up getting contradictory information'). Significant concern was focused on the facilities to support the project: materials were difficult to order, and access to workshops was not always easy to arrange; and yet 12 students drew motivation from the realistic nature of the project. The analysis further provides a view on student learning outcomes, with 57 suggestions for improvements in the process that was followed and in the final solution.

Fifteen students completed the short questionnaire; each had taken a DMT project during 2003-04. While the data from the questionnaire is not as rich as that from the project critiques, it confirms the general thrust of the findings from the project critiques, and also provides data on students' intentions for further study and for careers. From the 78 comments that have been categorized, at least 37 directly relate to technical aspects of the projects. However, team work also appears as relevant, as does the motivation from the realistic nature of the project and the developing world context.

The importance of the team work process also emerged within the critiques (139 comments). The students claimed in the critiques that their teams had generally worked well (32 comments). In particular, the students noted an appropriate division of the workload (on 19 occasions, e.g. 'I felt that each team member did the tasks that suited their strengths'), employing specific communication strategies (34 comments, such as 'Each group meeting had specific areas for discussion') and the use of team roles. In a limited number of cases a student observed that one or more other team members had not contributed fully. The students also made a range of comments as to how to improve the teamwork. It is interesting to note that the only issue from the critiques classed as an enabling factor was the division of some projects groups into two. Students raised this on nine occasions, commenting on the communication difficulties that resulted with the other group.

In their 35 comments on managing the project, the students emphasised the learning that occurred on how to manage a project. The projects afforded the students their first opportunity on the degree programme to manage a realistic project, so it might be expected that the students would gain practical insights into project management. Only 11 comments were made within the critiques on the use of project planning techniques. For instance, one student indicated: 'An initial schedule was drawn up in the first term and frequent project meetings were held.' Comments by the students on the management of their project instead primarily focused on possible improvements, with the need for improved planning, record keeping and scheduling all stressed.

Self-efficacy and awareness of learning

The critiques initially yielded limited information on self-efficacy of the students. However, when this area was revisited in light of a further consideration of the literature, the issue of students persevering in the face of difficult circumstances was recognized. This is a key issue, recognizing as it does that further work by the student could make a significant difference to the outcome of the project. During their critiques, 34 students identified one or more specific difficulties they had had to face during the project; and they also identified the strategies they had employed to overcome the difficulty. In three of these cases students noted that teamwork had helped them to face the difficulties, with five further students mentioning the realistic nature of the project work in this context, as according to one student: 'The process of acquiring material for manufacturing work on the project was not found very helpful . . . However this was typical of practical situations and gave the group a real life feeling of the project.' As Dweck(11) notes, there is a clear link between motivation and willingness to persist in the face of challenging circumstances.

A further area included within the indicators was that of the students' awareness of their own learning. Flavell(12) uses the term 'metacognition' to describe the higher order thinking that controls the process of acquiring knowledge. Substantial learning did apparently occur, with 108 specific suggestions made as to how the projects could be improved, but this does not constitute an explicit awareness of learning. Such awareness is more in evidence in the 21 comments in critiques explicitly claiming some enhanced ability, but no direct evidence emerged from the analysis that the students sought to control the way in which they learnt on the project. The project work itself provides the focus for their attention, rather than how they learnt while pursuing the project.

Attitudes towards the developing world

It would too much to claim that the students emerged with a rounded picture of the nature of relationships with clients in the developing world. One might instead say that an awareness is evident that the relationship needs to be managed, and that it was evident to the students that communicating with a client in a developing country often presented challenges. Some groups found it impossible to establish reliable forms of communication, for instance in one case, with a client in Zimbabwe. And when the initial design specification was inadequate for the purposes of the project, then it would be difficult to agree with the client a more appropriate specification. Indeed, the data outlined in **table 2** suggests that where the development context was concerned the students primarily raised enabling factors or difficulties with the process in their critiques. However, only 32 of the 41 students were involved in partnership projects, and this must be taken into account.

These comments by the students are dominated by references to the motivation that stems from working on a project that would be useful within the developing world; 26 comments were made to this effect. This is supported by data that emerges from the questionnaire, which asked whether students would be interested in taking on a project for their MEng the next year. Of those who responded, seven students indicated that they would be, six that they would not and two might possibly. In the event, six students who had completed DMT projects during 2003-04 did undertake such a project during 2004-05.

The questionnaire further asked about subsequent employment intentions: would the student prefer a job involving work with developing countries. Eight students indicated that they would prefer such a job; two students would prefer work that combined engineering within the both contexts, four students indicated that they might possibly be interested, but their choice would depend on other factors, and only one indicated that they would not be interested. One would not expect these intentions to be fully borne out, for instance in the face of difficulty of finding the desired form of work, but the intentions at least indicate current motivations.

EMERGING ISSUES AND CONCLUSIONS

In overall terms it is evident that the partnership between the charity, the College

Process	Enabling
Awareness of client needs and context (10) *It was found that micro-hydro turbines should be specifically made for a chosen environment.*	Motivation stemming from usefulness for developing world (26) *The mower project is the most interesting thing I have done on this course. Knowing that the machine would be used in the developing world as sufficient motivation to keep working.*
Difficulties in communicating with client (9) *The information required with regards to the availability of motors and filters in Zimbabwe never arrived.*	Limited availability of relevant information (11) *Perhaps it will be helpful if some technical details from Zimbabwe can be made available.*
	Limitations of initial design specification (9) *Our group had huge problems with the design specification for the lift tilt rotate mechanism. It often felt like X was unable to decide exactly what he wanted.*

Table 2: Categories of comments for process and enabling indicators within project critiques that relate to the context of the developing world, with frequency of comment and illustrative comment

and other professionals has provided a worthwhile educational experience for the students involved, with the factors that Edelson(6) identified as critical in the successful use of enquiry-based learning in operation. Student motivation has been particularly evident, stemming in part from the realistic nature of the enquiries and the usefulness of the engineering solutions. The tasks were sufficiently accessible given the students background, partly due to the reliance on intermediate technology. Resource constraints and teamwork processes were at times a limiting factor, but this perhaps added to the realistic nature of professional work.

Immediate lessons clearly emerged for the ongoing conduct of these projects; facilities and ordering processes for the students need further attention, as does the management of relationships with clients in the developing country. Project management and teamwork would also benefit from further scope attention, as would students' awareness of the need to persist in the face of complexity and of their own learning. One might ask the students to track the difficulties they encountered and the strategies they employed to overcome them, and then require reflection on this data, and thus on their self-efficacy. It will also be worth exploring whether strategies devised in other learning contexts to promote metalearning are likely to be effective: an adapted version of Meyer's(13) Reflections on Learning Inventory might provide a means to generate feedback.

Many universities, however, would be wary of adopting this model within their own contexts given the financial or organizational demands of initiating a charity. Perhaps the primary interest in this study lies less in the wholesale adoption of such a partnership, and more in the issues that emerge for learning that is based around a process of enquiry, and for wider purposes of education.

Students involved in the projects raised issues of fairness, an issue that would be expected with realistic projects. In this case we have partnership and non-partnership projects, and projects carried out in two groups, as well as different projects carried out by further students on the degree programme. One might, of course, expect certain students to choose to devote more work to a project, but one could argue that this should be seen in terms of extending a project or enquiry rather than its basic completion. Clearly it will not be possible to even out the complexity, but where projects inherently include complications tutors will need to address the issues. It might be tempting for a tutor to give greater advice in this setting, but this should be resisted with enquiries that are led by students. Tutors could offer additional facilitation, other support, or focus on the expected learning outcomes of each project. One of the advantages of learning based on a process of enquiry concerns the breadth of abilities that can be developed (something noted, for instance, with problem-based learning[2]). It might be possible to ensure projects include a similar level of complexity (e.g. either a partnership project or two groups of students working on a single project) even if they do not all develop exactly the same abilities.

Where realistic projects are concerned, or enquiries with significant scope for varied lines of enquiry, it would thus be advisable to put a systematic process in place to ensure fairness, perhaps using a proforma covering range of expected learning outcomes, levels of facilitation, resources and other relevant support available. For instance, if the ability to deal with a client is not one of the intended outcomes of the learning process, then care should be taken to ensure that this does not become problematic in one context when another student is not dealing with a client. In this case, reliable communication systems, a carefully negotiated design specification and an initial investigation of available information resources might all need to be in place before agreeing a partnership project.

It is also worth considering student motivation as an enabling factor in an enquiry, supporting as it does self-efficacy and the willingness to drive an enquiry to a conclusion. Further research could explore how the sources of motivation evident in this study are mediated socially, perhaps through focus group work with students. Specific networks of social interactions, termed 'figurations' by Elias(14), are know to play a significant role in shaping students internalized modes of thought and their permanent dispositions, the habitus of Bourdieu(15). But even now we can see that these projects address student motivation at a number of levels: realistic scenario, including engagement with a client and other professionals; membership of a team; creation of a product for use within the developing world. Education cannot be isolated from human concerns; and this includes issues such as world poverty. Paolo Freire(16), for instance, linked education based around student enquiry with revolution. Many universities will be unwilling to connect education and oppression, but they might find a more engaged student body by linking wider human concerns with student enquiry. Motivation comes in significant part from education that serves others – and not simply self-interest.

This evaluation has thus explored a human basis for education: realistic enquiries supported a charity. While we recognize that this stage of the research has drawn on a relatively limited set of data, we have been able to draw initial conclusions on the effectiveness of the partnership, and also highlight a number of key issues. There is evidently scope for engineering students to assist in contributing solutions to world poverty, particularly in the early development of positive attitudes and experience for working with the developing world. Other disciplines as well may find ways to frame education that serves the interests of others, thereby drawing on a deep well of student motivation.

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AN INTEGRATED APPROACH TO INTRODUCING SUSTAINABLE DEVELOPMENT DESIGN CONCEPTS TO THE CURRICULUM

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ABSTRACT

As part of the Royal Academy of Engineering Visiting Professors Scheme, a group of staff from the faculties of Engineering and Architectural Studies at The University of Sheffield is working towards the introduction of sustainable development (SD) design teaching. Design for SD is acknowledged as being the critical issue for the 21st Century and it is therefore essential that students have skills in this area.

Initially SD teaching material has been introduced in the early years of courses, with the ultimate aim being a large interdisciplinary group design project in years 3 or 4.

A module is currently being run in Civil and Structural Engineering for fourth year students. The project being undertaken is based on a site currently under development by Yorkshire Forward in Leeds and revolves around an urban village redevelopment scheme.

The project encompasses all aspects of sustainability including social as well as environmental and economic issues and the views of all stakeholders are being incorporated. This approach is unique for engineering students, but will greatly enhance their skills portfolio.

The interdisciplinary project, will also allow students from different fields to work together and gain valuable experience they will need when moving into employment. Management of the course is carried out using WebCT and resources such as site videos, interviews with stakeholders and examples of planning meetings are available to students.

This paper outlines the structure and mechanisms used for introducing SD teaching and gives details of the design courses being run and developed for years 3 and 4.

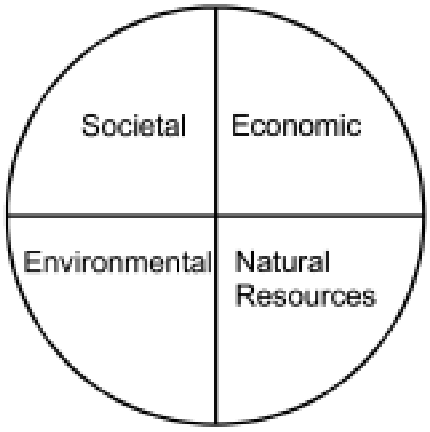

Figure 1: Key areas of sustainable development

INTRODUCTION

Sustainable Development (SD) has become an increasingly prominent theme for engineers since the 1992 United Nations Conference on Environment and Development at Rio de Janeiro. It has been defined as ‘Development that meets the needs of the present without compromising the ability of future generations to meet their needs’(1). There are a number of models for SD, one of these splits it into four areas. As shown in **figure 1**, these are defined as societal, economic, environmental and natural resources. It is not unusual for engineers to deal with the last three, but engineers in the past have rarely been exposed to issues relating to society. This, however, is changing and as such the next generation of engineers needs to be aware of its responsibilities in all four sectors.

SD has been described by many as one of the most important issues for engineers for this century. Increasing legislation affecting, for example, how products must be treated when they reach the end of their life, such as white goods (WEEE) and cars (ELV management); energy use in buildings; use of pesticides and plastics in farming and landfill quantities; means

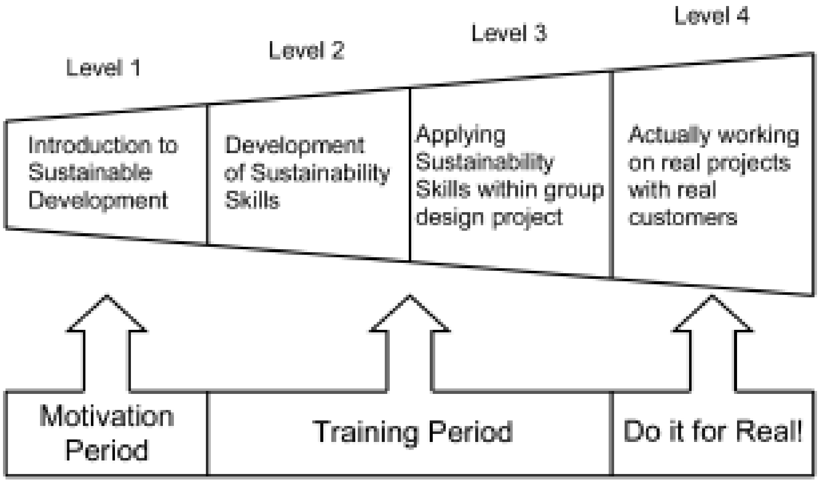

Figure 2: Developing the 'sustainable' engineer model

that it now must be a critical part of the design processes and systems used in these areas.

The result of all this is that the current generation of practising engineers need to become more informed about sustainability, but also that in order for the next generation to be able to design more sustainable products, buildings and systems etc. when they enter the profession, teaching at undergraduate level needs to incorporate the principles of design for SD.

Many organisations have recognised the importance of SD. One of these, the Royal Academy of Engineering, has set up a scheme for the appointment of Visiting Professors in Engineering Design for Sustainable Development. The primary aim of the scheme is to assist in the generation of teaching material for SD across all areas of engineering, not just design, and enhance the understanding of sustainability amongst both students and academic staff. 26 appointments have been made so far, one of these being at The University of Sheffield.

EMBEDDING SD AT THE UNIVERSITY OF SHEFFIELD

At the University of Sheffield a broad approach has been taken to embedding SD and a large number of Departments are involved across two Faculties including: Civil and Structural Engineering, Chemical and Process Engineering, Mechanical Engineering, Town and Regional Planning, Architecture and Landscape.

The overall philosophy for embedding teaching material is outlined in **figure 2**. This is based around a four year masters level degree such as an MEng. Obviously it can be tailored appropriately for varying degree lengths.

At each level key knowledge and skills have been identified and a matrix has been set-up. Obviously different Departments will pick and choose from this matrix to find the best options for their needs.

The overall plan for embedding SD into the curriculum is shown in **figure 3**. In the early years of the scheme, the focus has been on embedding the basics into the early years of courses and creating streams of SD teaching, which has now been achieved.

Generic teaching materials have been created including an online quiz that can be utilised by any department and a case study site has been established. Innovative teaching aids based on a WebCT environment are also being created, including a visual database with panoramic views and video clips of stakeholder interviews. The sustainability assessment tool developed by Arup, called SPeAR (Sustainable Project Appraisal Routine), is also being used. This essentially is used to assess how a scheme performs in the four areas of SD shown in **figure 1**. **Figure 4** shows a typical plot indicating how the scheme rates in the four areas and their subcategories in terms of SD principles.

	2003/4		2004/5		2005/6		06/7-07/8	
	S1	S2	S1	S2	S1	S2	S1/2	S1/2
(a) Teaching Materials								
Core Y3/4 Design Module								
Mechanical Eng. Design aspects of core								
Chemical Eng. Design aspects of core								
Civil & Struct. Eng. SD thread, Y1-Y3								
Post-graduate unit								
Portfolio of inter-departmental group design projects								
(b) Other activities								
Attendance at RAEng workshops		*		*		*		*
Training of academic staff								

Figure 3: Long term plan for embedding SD into design teaching at the University of Sheffield

One of the key elements of the scheme at Sheffield has been to enhance the interdisciplinary nature of teaching. In the real world the students will have to work with engineers from a range of disciplines so to already have done this will help them immensely and enhance their employability. The ultimate aim is therefore to create an interdisciplinary final year module on design for SD. This will be difficult as each department runs courses in different ways, but it is a realistic objective to have students from different departments working with each other, even if only for a short time.

The case study site that has been selected is the Holbeck Urban Village. This is a Yorkshire Forward development area near to the centre of Leeds. The vision is to develop it using sustainable principles over a ten year period. The site is currently only partially developed so it will be usable for a number of years as a case study and the students will be able to see how it has been done first hand.

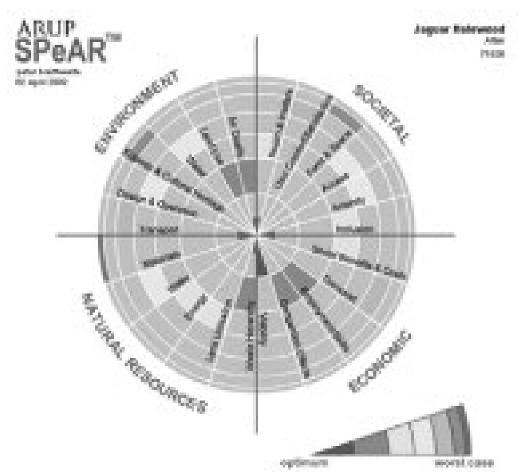

Figure 4: Example of the SPeAR output for a typical project

There are a number of interesting aspects to the site, which is mainly industrial, and includes a number of listed (currently empty) buildings, including the Temple Mill, as shown below in **figure 5**, which has a 'green' roof. There are patches of contaminated land; small businesses set up in viaduct arches; a disused railway line and a canal.

The areas developed include mill buildings converted to offices and factory buildings converted to flats and apartments. This means there is plenty of scope for projects covering all aspects of engineering and possible work for architects and town planners.

A final year module has been running in Civil and Structural Engineering now for two years on SD, which includes project work based on the Holbeck site. Some examples of the students output are shown in **figure 6**. Here they were asked to come up with plans for the 'South East Gateway' of the site.

Student feedback was very positive. They felt that they had learned something new and they were keen to put some of the concepts into practise when they go out to work in the real world.

SD TEACHING IN THE DEPARTMENT OF MECHANICAL ENGINEERING

Clearly, with the competing demands of an engineering education system, it would be impossible to have modules at each level totally related to SD. The approach in Mechanical Engineering has been to identify teaching already in place which relates to SD and where there are gaps to provide

Figure 5: (a) Temple Works (listed); (b) Small business locations; (c) Disused land

lectures, case studies or small assessments to provide a stream through the levels that matches the requirements of the model shown in **figure 2**.

Figure 6 shows the modules taken by students in the Department of Mechanical Engineering at each level in the MEng programme. Modules highlighted with a dark border incorporate some element related to SD (titles for these modules are given in **table 1**). As can be seen

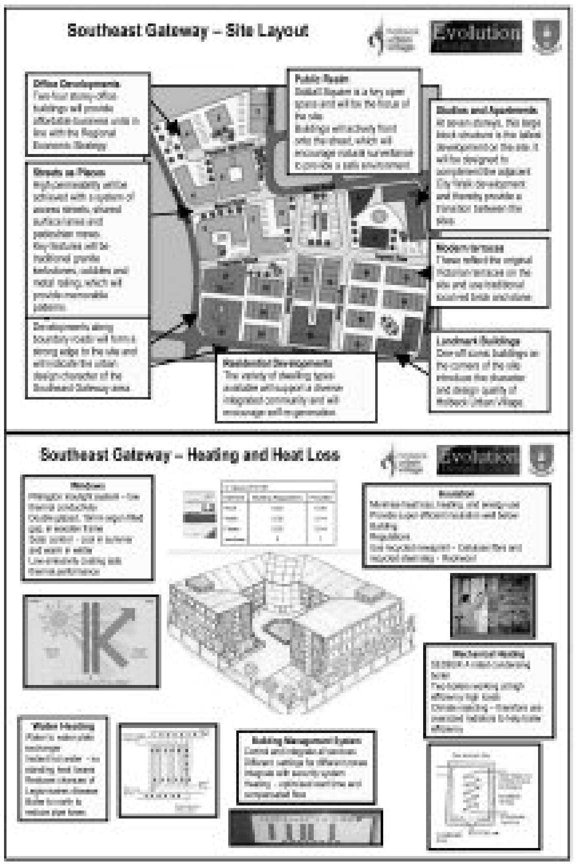

Figure 7: Student output from the design for SD course in civil and structural engineering

there is an almost complete stream of SD teaching.

In MEC115 students have to carry out an individual project to design something to make it more sustainable. This is to encourage some creativity, while learning how difficult it may be to achieve SD. A large number of ideas have been generated for a huge range of products and services including greetings cards, nappies, shop receipts etc. A similar exercise is run in MEC119 where the students redesign something to make it more 'inclusive' – a social aspect of SD. This again has led to a large number of ideas some of which are shown in **figure 7**. The students have enjoyed the freedom they are given in these projects and have come up with some very novel ideas. In MEC114 a 'words into numbers' exercise is set in which students compare the energy used driving to a recycling facility with some glass bottles with that saved by not making new glass. This shows them that there is much to consider when trying to be sustainable!

Sem 1	Sem 2	Sem 3	Sem 4	Sem 5	Sem 6	Sem 7	Sem 8
MEC115	MEC119	MEC205	MEC209	MEC304	MEC307	MEC401	
AMA149	AMA150	AMA253	AMA254	MEC306			
MEC114	MEC102	MEC202	MEC207	MEC302	MEC316	CPE414	MEC4XX
MEC171	EEE111	MEC204	MEC210	MEC305	MEC308	MEC402	MEC412
MEC110	MEC116	MEC201	MEC206	MEC301	MEC309	MEC403	MEC413
MEC113	MEC118	MEC203	MEC208	MEC303	MEC310	MEC404	MEC415
					MEC311	MEC405	MEC416
					MEC312	MEC406	MEC417
					MEC313	MEC407	MEC419
					AMA340	MEC409	MEC424
						MEC410	
						MEC411	

Design
Mathematics
Solid Mechanics and Materials
Fluid Mechanics
Engineering Management and Manufacturing
Mechanics, Control and Electrical Engineering
Optional Modules
Modules including SD

Figure 6: Subject streams in mechanicale engineering teaching highlighting SD content

The courses in the second and third years focus on materials and energy and again are small parts of modules, except the Solar and Wind Option. The Group Design Project is where they first start to apply the knowledge they have acquired. Topics for this have included addressing the transport problems in cities and between cities and wheelchair design.

A final year option (MEC4XX) has been proposed that will run next year, which is similar to the module run in Civil and Structural Engineering. An overview of the module content is given in **figure 8**. There will be a big focus on the social elements of sustainability using a case study from Sheffield that the students may well be stakeholders in themselves. A mock planning meeting will take place with students representing different stakeholder groups. The new module will also use the Holbeck site for the main project. A site visit will be used to allow students to take pictures of what they think is significant in terms of sustainability. This will also help build up an image database for the site. There is a time overlap with the Civil and Structural Engineering module, which will allow the students from both departments to interact and work together.

Module Code	Module Title
MEC115	Design and Manufacturing
MEC114	Mechanical Eng. Techniques
MEC119	Design Skills
MEC207	Materials Processing
MEC302	Integrity of Materials and Components
MEC306	Professional Responsibilities of the Engineer
MEC316	Solar and Wind Energy
MEC307	Group Design Project
MEC414	Environmental Protection
MEC4XX	Design for a Sustainable Environment

Table 1: Modules incorporating SD teaching

CONCLUSIONS

Design for sustainable development is one key issues for engineers for this century and legislation is being introduced to enforce its introduction. As such the new generation of engineers need to have the knowledge and skills to cope with this.

A team of academics from a number of Engineering departments as well as Town and Regional Planning, Architecture and Landscape Architecture is working towards embedding teaching on design for SD into the curriculum, promoting the creation of generic and innovative teaching aids and interdisciplinary working to further enhance student skills.

The initial introduction of the basics at lower levels is complete in a number of departments and one final year module is in place where students put these skills into practice on a real case study site.

Other than the successful introduction of SD design teaching, working as an interdisciplinary

Wk	Lecture/Tutorial	Lecture/Tutorial	Class Session Activity (2 hours)
1	Introduction to the course	Introduction to Sustainability	Teambuilding exercise
2	Sustainable Urban Redevelopment Sustainability presentation topics assigned	Dreamweaver session	Work in groups to prepare a presentation on one of a number of sustainability topics
3	Introduction to Holbeck Urban Village Project Introduction to the images gathering, plan and energy assessments	Tutorial on site visit plans	Site visit (**Assessment** - groups to take pictures during the tour of the site of significant features related to sustainable urban redevelopment which they incorporate into a webpage
4	"Green" Energy	**Assessment** - Presentations on sustainability topics	**Assessment** - Presentations on sustainability topics (students mark each other and give feedback)
5	Sustainability Appraisal Tools 1	Sustainability Appraisal Tools 2	SPeAR workshop
6	Social Aspects of Sustainability (using stakeholder perceptions from the Holbeck project)	Holbeck project group work	Holbeck project group work
7	Sustainability and Transport (using Supertram case study) Introduction to stakeholder exercise	Tutorial on Holbeck project	Stakeholder exercise group work – groups to take on the role of a stakeholder in the Supertram project and prepare a case
8	Sustainability Legislation	Tutorial on stakeholder exercise	**Assessment** – Groups present their cases on the Supertram case study and are also given the task of preparing arguments against each other's cases
9	Joint lecture with Civ. Eng. Students	Joint lecture with Civ. Eng. students	Presentations with Civ. Eng. students
			Assessment – Report hand-in and Posters and Presentations with VP and industry experts

Figure 8: Overview of new design for sustainable environment module (MEC4XX)

team has had benefits for the academics involved. Sharing of teaching material, teaching methods and ideas has taken place and the new contacts made have helped in creating opportunities in other areas.

Streaming of SD teaching material in the Department of Mechanical Engineering is almost complete and students are relishing the design projects that have been set and are creating some novel design solutions, while learning key skills that will enhance their employability.

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SUSTAINABLE DEVELOPMENT FOR ENGINEERS: DEVELOPING RESOURCES TO DELIVER TRANSFERABLE SKILLS

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ABSTRACT

This paper illustrates how Cambridge University Engineering Department is building on its experience of introducing sustainable development concepts into undergraduate teaching and use of a range of delivery methods. Importantly, it explores ways of embedding the material into existing technical courses.

Applying the concepts of sustainable development to engineering subjects addresses the external and societal context but also professional skills and attitudes and systems thinking, which provides a framework for consideration of many requirements and can be illustrated when exploring trans-disciplinary projects and issues.

Professional skills and attitudes are explored when considering the value-laden decisions and ethical implementation that is so central to projects that contribute to sustainable development. In particular, the external focus that requires a wide spatial perspective when it addresses issues of global concerns, and the longer temporal perspective necessitated by considering issues of inter-generational equity and the needs of future generations.

This paper aims to demonstrate the close synergy between sustainable development education for engineers and the broader transferable skills required by professional engineers. It provides a case history of previous teaching and an outline of future plans to increase both the effectiveness and the scope of integration into the wider engineering curriculum at the University.

INTRODUCTION

Cambridge University Engineering Department (CUED) has made a concerted effort to embed the concepts of sustainable development into its undergraduate degree programme. This effort has been facilitated by a project to improve engineering education by producing high-quality teaching material in the form of 'instructor resource modules' to meet the immediate needs of the department but also the wider aim of open knowledge sharing through a free global website.

Motivations

Incentive to more widely apply the inclusion of sustainable development and transferable skills comes from a number of directions.

Visiting Professor CUED is a participant in the Royal Academy of Engineering (RAE) scheme for Engineering Design for Sustainable Development(1) and has benefited from a Visiting Professor (VP) in the subject since 1999.

The scheme, which brings eminent engineering practitioners from industry to contribute to embedding sustainable development concepts into academic teaching, greatly raised the profile of sustainable development issues within the department.

Other Universities Recognition that other universities are providing teaching on sustainable development (including those 25 other universities currently involved in the RAE VP scheme) has been a major driver towards considering inclusion within the Cambridge University engineering degree.

Commitment of a number of universities worldwide to the Conceive-Design-Implement-Operate (CDIO) syllabus, including four UK universities (Lancaster University, Queen's University Belfast, Bristol University and Liverpool University) demonstrates a growing dedication to the teaching of transferable skills for engineers. This attitude to teaching, based on the practical application of principles, recognises a need for students to better understand the context in which they will work.

Accrediting Institutions Also, demand from accrediting professional institutions for inclusion of sustainable development into accredited degree courses has increased in recent years. With the launch of the Engineering Council UK new 'UK Standard for Professional Engineering Competence'(2) (UK-SPEC) in December 2003 exposure to the principles of sustainable development and associated transferable skills was given far greater prominence than with previous requirements for professional membership. With this comes an incentive for universities to include knowledge of sustainable development in their courses to help students to meet this requirement.

Student Demand In addition, students at CUED have indicated that they want the inclusion of broader contextual issues in their course. The large numbers enrolled in the specialist elective course in the final year and the increasing demand for projects that have sustainable development components or context demonstrates this.

Department Strategy In September 2004 CUED launched its new Department Strategy that acknowledged sustainable development as one of three main emerging research themes. This action has considerably raised awareness of the issues associated with sustainable development within the department, and indicated the relevance to engineering.

Establishment of the Cambridge University Engineering Department Centre for Sustainable Development(3) has further helped to support embedding the concepts of sustainable development in academic research and facilitated development of quality teaching material.

INTRODUCING SUSTAINABLE DEVELOPMENT CONCEPTS INTO EXISTING TECHNICAL COURSES

In light of these external and internal drivers for change, the department made a commitment to include the concepts of sustainable development into its courses.

It is recognised that teaching sustainable development as an additional subject area is not effective in terms of practical application. More useful is using incorporation of the concepts of sustainable development into existing courses to highlight and explore a range of issues that would otherwise be neglected.

It is important that sustainable development be embedded into the entire curriculum as an ongoing thread rather than added on at the end as an optional specialism. So while the addition in 2001 of a fourth-year module in Engineering for Sustainable Development proved successful for awareness-raising within the department, the pressing need was for the concepts of sustainable development to be integrated throughout the existing technical-based courses offered by the department.

Sustainable Development and Transferable Skills

It was recognised that teaching sustainable development to engineers also provides the opportunity for inclusion of useful 'transferable skills' of the type advocated by the CDIO syllabus developed at MIT(4). This includes developing aptitude in the areas of societal context, professional skills, and system thinking and together can help to define a framework useful for consideration of trans-disciplinary projects and issues that are commonly encountered when addressing sustainable development.

Societal Context Appreciation of the societal context in which engineers operate is a vital part of delivery of sustainable development ideals. Recognising the importance of: engineers' roles and responsibilities, stakeholder participation, and a global perspective all contribute in this skill area and are key tools for considering sustainable development.

Professional Attitudes Similarly, development of a student's professional skills and attitudes addressing wider spatial and temporal perspectives permits exploration of holistic thinking, dealing with uncertainty, ethical practice, and effective resource management, all necessary when addressing sustainable development projects and problems. Also, students can be encouraged to improve their teamwork and communication skills.

Systems Thinking These can all be drawn together in an example of systems thinking where inter-related actions and their consequences can be examined analytically.

Issues associated with sustainable development are often complex and value-laden. A pre-requisite to embedding these concepts into undergraduate teaching is some exploration of what is trying to be achieved. Florman(5) raises this difficult question 'We are agreed that we want to do the right thing. But how are we to determine what the right thing is'.

Essentially, the philosophy adopted at CUED has been not to provide conclusive answers – we do not attempt to tell students how to build the ultimate sustainable bridge – instead the emphasis is on helping students to develop the skills and background knowledge necessary to enable them to ask better questions. These become manifest as useful transferable skills such as those outlined above. Equipping students with such abilities has been the emphasis applied to the undergraduate course material.

Survey

To implement this pledge effectively first involved investigating the overall content of the existing degree programme and identifying areas within the course where sustainable development could be appropriately and feasibly incorporated.

In an effort to establish the level of sustainable development and transferable skills teaching throughout the undergraduate programme, an extensive survey of course content coupled with staff perception and motivation was carried out.

Delivery Methods In consultation with the teaching staff responsible assessment was made based on the levels of participation achieved. A distinction is made between passive and active learning.

At the first level of engagement the lecturer provides students with information who receive it passively. This can be thought of as the traditional style of class teaching, essentially one-way, from the instructor to the student.

At a higher level of engagement students are required to participate in some sort of active learning such as participation in a discussion or role-play, carrying out example questions, or doing an assignment.

At the top level of participation the concepts of sustainable development are fully embedded into the material and form the main purpose or content, the students actively engage with the broader complex issues of sustainable development in context. Here they may be required to engage in some level of personal judgement on a subject or an issue, but be sure to back up their statements and position and present it in an effective and reasonable way.

The assumption is that greater participation by students will develop into greater appreciation of subjective value-judgements, use of data, and trade-offs that become important aspects of decision making around many complex sustainable development issues of the sort engineers frequently encounter in the professional roles.

Initial Findings From the initial survey of teaching content, a number of significant points have been brought to light. The presence of the RAE Visiting Professor in the department since 1999 has certainly served to considerably raise the profile of sustainable development in teaching of the engineering degree at Cambridge University. However, it must be noted that there previously existed a range of courses that contained some level of content about sustainable development. These could, in the majority of cases be thought of as having implicit sustainable development content. In recent years an effort has been made to more explicitly include the concepts of sustainable development into many undergraduate courses.

Summary The collated data from this survey suggests that all students have some contact with sustainable development concepts in their first year courses, but this is often at a fairly basic level. Specialist subjects in the different engineering fields can accommodate more participatory approaches to teaching and provide a higher level of competence through engagement with the issues.

There is a range of opportunities for introducing the concepts of sustainable development into the degree using a variety of delivery methods as appropriate to the content of the material and/or the format of the class. To date, the main contributions have been made in specific courses as described below.

CASE HISTORY OF TEACHING

At CUED the undergraduate engineering programme is a four-year degree culminating in Master of Engineering (MEng) qualification. A small number of students each year elect to take the option of a Bachelor of Arts (BA) on successful completion of their third year. Part I of the degree is a general engineering introduction covering the major engineering disciplines except for Chemical Engineering, which is taught in a separate department. Specialisation occurs in Part II (see **table 1**).

Year 1	Part IA	General Engineering
Year 2	Part IB	General Engineering
Year 3	Part IIA	Specialist Engineering
Year 4	Part IIB	Master of Engineering

Table 1: Cambridge University Engineering Degree

PART IA – FIRST YEAR (GENERAL)

In the first year, students are taught all subjects, often as one large class. Sustainable development has been substantially incorporated into the following subjects:

The Engineer

In Society All students participate in this introductory course. Since 2001-2 there has been a specific section on sustainable development included in this course. While not the only featured subject it forms a significant part of the course that looks more generally at the philosophy of engineering practice. It is presented in a large lecture theatre to an audience of over 300 students making meaningful participation by the students very difficult. However some success can be achieved and the course serves to provide a good opportunity to engage students with the basic principles early on in their degree, perhaps building on knowledge they have gained previously at school level.

First Year Expositions

The Expositions course that runs in the first term of the initial Undergraduate year has provided a useful vehicle for exploring the issues of sustainable development and transferable skills such as communication. The course demands compulsory attendance by all students and is taught in groups of up to twelve students. This close contact with students at a formative time is a valuable opportunity to explore the fundamental context of engineering.

For individual module leaders who are interested in including the issues of sustainable development there are several good opportunities. The structure of the course is in three parts: Journal Club, where students research and give an oral presentation on a subject of their choice as featured in a recent engineering journal; Report Writing, where students produce a formal report of a structures laboratory experiment; and Discussion/Debate, where students debate a contentious issue to demonstrate their argument and reasoning skills.

This is one course where a progressive improvement in embedding the teaching of sustainable development and transferable skills can be demonstrated by a general move from implicit coverage of sustainable development concepts to a more explicit inclusion and a greater emphasis. In recent years, several of the lecturers have taken the opportunity to increase the sustainable development component in their facilitation of this course.

PART IB – SECOND YEAR (GENERAL)

The second year of the undergraduate degree is predominantly general, but students do begin to specialise in the final term by taking elective modules from the different engineering disciplines. Generally students are taught the technical elements of engineering science, mostly as one large class so the full student cohort will receive any sustainable development content in the core courses.

Currently there is some effort to incorporate sustainable development concepts into some of these core modules, but at present this is limited to contextual application and is largely driven by the lecturing staff's own commitments. There is certainly scope for more material to be added at this level.

PART IIA – THIRD YEAR (SPECIALIST BA)

In the third year, students fully specialise into the various engineering disciplines. Groups representing the engineering fields provide courses in the different areas.

Similar to the second year of the course, the emphasis is on teaching essential engineering science, but there is considerable scope for inclusion of sustainable development concepts and since classes are smaller, in the region of 30-50 students on average, there is opportunity for more participatory modes of delivery.

It is also in the third year that those students electing to take the Manufacturing Engineering Tripos (MET) route separate from the main student body to pursue a dedicated curriculum for either one or two years.

Manufacturing Engineering Tripos (MET1 & MET2)

After the second year, students have the option of taking a specialist Manufacturing course for the final two years. MET1 and 2 respectively replace the third and fourth year options offered to the rest of the department's undergraduate community. MET has a more industrial application focus and comprises special projects, group work and many links with sponsoring manufacturing companies and consultants.

There has long since been a strong sustainable development focus to the Manufacturing courses and the division has its own Sustainable Manufacturing Group that undertakes high-level research and contributes to teaching.

PART IIB – FOURTH YEAR (MEng)

The structure of the final year is open elective modules in a specialist field. Some modules have prerequisite courses but most are open to all. First year PhD and research MPhil students are each required to take three modules from the options offered to Part II undergraduates and this leads to mixed classes in some cases.

Engineering for Sustainable Development

As part of the initial commitment to the RAE VP scheme, a new fourth-year elective module was developed and first ran early 2001. This module took the form of a coursework-assessed taught elective module open to all engineering disciplines in CUED and with no pre-requisites. This course featured case studies based on the main subjects of waste, energy, and environmental impact.

In later years the course has also included Change Management, and Water as key themes, and it has become the flagship course in sustainable development in the department. The module has been updated each year and has proved consistently popular with students from a range of engineering disciplines.

Despite the reasonably high numbers of students in the class, the emphasis has been

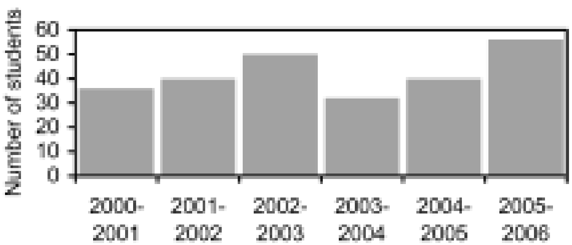

Figure 1: Sustainable development elective

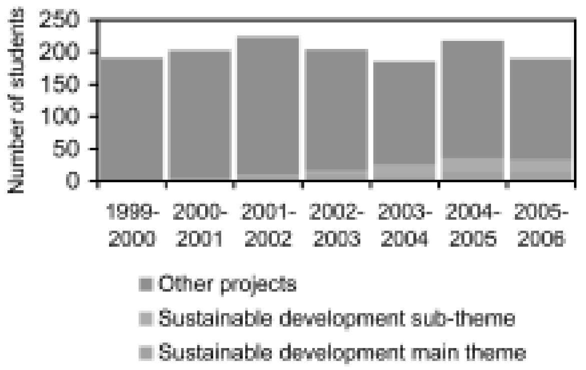

Figure 2: Fourth year projects

on participation by the students. A combination of role play, discussion, quizzes and a wealth of guest lecturers from industry have facilitated the active learning dimension of this course.

However, responses from both staff and students in the department have suggested that an elective in the final part of the degree limits the impact that it can have on students.

Fourth Year Projects

Another place where sustainable development issues have been increasingly included is in the Fourth Year Project, a 12,000-word report on research carried out by the student.

Since broad titles focussed on sustainable development were first offered in academic year 2000-1 the number of students undertaking projects relating to application of sustainable development concepts has increased markedly. The demand for projects with a major or minor focus on sustainable development has continued to grow over that period.

FUTURE PLANS

As has been demonstrated by the survey of teaching activity in the department, full commitment to the proposal to embed sustainable development into the curriculum requires inclusion of considerably more content. To facilitate this, it was recognised that teaching staff required assistance in sourcing reliable material for inclusion within their existing courses. It is not the intention that

Improved engineering education project (7)

material currently covered must be displaced to make space for a block of sustainable development teaching but rather that concepts can be illustrated through material that also addresses the wider issues.

For instance a course to examine the structural properties of a range of materials may be augmented by raising questions about social and environmental impacts of manufacturing that material, the waste implications at end of life, and the economic balances that must be made when assessing appropriateness for a given application. All of these aspects can then incorporate a number of sustainable development concepts and transferable skills.

Instructor Resources

To facilitate inclusion of transferable skills and sustainable development into a greater range of undergraduate courses a current project, funded by the Cambridge-MIT Institute(6) (CMI) aims to contribute towards Improving Engineering Education (ImpEE).

This project focuses on providing material to assist individual in the form of specific 'Instructor Resource Modules' to help them in the effective delivery of sustainable development concepts and transferable skills within their existing courses.

The aim of the ImpEE project was to develop useful materials for teaching staff. There was an identified need for background information that could be used by instructors delivering 'traditional' technical engineering courses. What was required were examples of ways of incorporating sustainable development and transferable skills into existing courses.

Engagement with staff

Crucial to the progress of embedding sustainable development and transferable skills into the degree programme was successful engagement with teaching staff. In the case of CUED, the process has been incremental over a number of years. As demand for sustainable development content was acknowledged and ways of embedding aspects into the existing technical courses was demonstrated, then more staff have become involved.

Initially ‘champions’ from each engineering discipline were established and these people helped to identify the type and format of material that could be usefully associated with the existing courses. From this, particular technical courses were chosen so that example resources could be developed tailored to a specific audience.

The ImpEE project team is working with individual lecturers at all levels of the degree and across all engineering disciplines to facilitate production of useful instructor resources.

Availability of Material

While the material was initially developed with the CUED courses in mind it is anticipated that the instructor resources developed will have value for engineering educators everywhere.

The structure of the material developed through the ImpEE project has been tailored to that required of busy lecturing staff and is intended to be accessible at various levels from the very basic to the highly detailed. The objective is that all material presented is reliable and freely available and free from copyright or restrictions. This includes use of copyright free illustrations, and referenced data and statements.

The instructor resources developed through this project are openly available on the ImpEE website and are free for use outside the university. All material is quality-assured, well sourced, reliable, and copyright free.

CONCLUSIONS

Engagement with active teaching staff is an essential pre-requisite to changing an existing curriculum content. The experience of CUED is that, typical of other large and complex organisations, a combination of bottom-up and top-down pressure is require to drive change, but then a considerable resource is necessary to facilitate change and truly embed the alterations.

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