An Inter-Disciplinary, Problem-Based Approach to Educating Engineers in Sustainable Development.

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***Abstract* - In 2005, both the National Academy of Engineering in the US [1] and the Engineering Council in the UK [2] produced statements that explicitly incorporated the need for sustainable development. In the same year, the University of Manchester approached the Royal Academy of Engineering to sponsor a pilot project for an inter-disciplinary course on sustainable development in undergraduate engineering and physical sciences programmes. That project features a problem-based approach with five student exercises covering a range of sustainability issues. Students come from four disciplines and work together in small inter-disciplinary teams, tackling problems that new graduates might realistically be asked to pursue. There is strong focus on teamwork and on the challenges of sustainable development, including cultural, economic, environmental and social imperatives. The final assessment is divided between demonstration of skills and understanding of course content. The pilot is a step in developing imaginative and persuasive proposals for change in education for professional practice.**

Key Words- Problem-based, curriculum, sustainable development .

INTRODUCTION

Sustainable development has risen up the international agenda in recent years and for some us this has been concurrent with the rise of interest in the overlapping concept of global citizenship. Elsewhere [3], two of the authors have pointed to the need for an inter-disciplinary approach to the major issues that the world faces in the future and have suggested the overlapping of interdisciplinarity with both global citizenship and sustainable development. Whilst we have been lobbying for this proactive, inter-disciplinary, student-centred approach, professional engineers have also been quick to adapt to changing circumstances.

In the US in 2005, the National Academy of Engineering suggested [1] that '[the] future engineering curriculum should be built around developing skills and not around teaching knowledge… We must teach future engineers to be creative and flexible, to be curious and imaginative.' At the same time in the UK, the Engineering Council produced new standards of engineering competence [2] that explicitly included sustainable development. The standards document states that: '[Engineers have a] crucial part to play in minimising risk to the environment, and in bringing about sustainable development, not only in the UK but throughout the world.'

Also in that same year, the University of Manchester approached the Royal Academy of Engineering to sponsor a pilot project for an inter-disciplinary stream on sustainable development in undergraduate engineering and physical sciences programmes. In 1998 the Royal Academy of Engineering had introduced a scheme for Visiting Professors in Engineering Design for Sustainable Development. The appointees worked with individual universities in the development of teaching materials, but much of the outcome has not been publicly available. The Royal Academy of Engineering agreed to appoint Charles Engel, a well-known figure in the field of problem-based learning (PBL) and medical education, to one of these Visiting Professorships to provide creative guidance to the project. The pilot project started in February 2007 and features a problem-based approach with five student exercises covering a range of sustainability issues. Students come from four disciplines - Civil Engineering, Electrical Engineering, Mechanical Engineering and Earth, Atmospheric and Environmental Sciences - and work together in small inter-disciplinary teams, tackling problems that new graduates might realistically be asked to pursue. There is a strong focus on teamwork and on generic and profession-specific competences for engineering practice. These are focused on implementing change towards sustainable development, including cultural, economic, environmental and social imperatives, identifying and overcoming barriers to change and understanding wider consequences in the longer term. The team facilitators are Postdoctoral Research Assistants from an even broader spectrum of disciplines, including Chemical Engineering, Chemistry and Computer Science, as well as the student disciplines. The final student assessment is divided between the demonstration of skills and understanding of course content. This pilot is viewed as a step towards developing more imaginative and persuasive proposals for curriculum design to embed change in professional practice. One such possibility would be the development of a 'strand' that runs through all three or four years of an undergraduate degree.

DESIGNING THE CURRICULUM

The apparently anomalous appointment of a prestigious figure from a field other than engineering to the Visiting Professorship serves to underline our emphasis on developing an educational approach geared to facilitate the embedding of a student-centred inter-disciplinary course. To reach this stage there has already been considerable groundwork by the project team and this is well described elsewhere [3]–[5]. The aim of the pilot study is to familiarize students with aspects of sustainable development and their management in professional engineering practice and to develop related abilities and skills. This is within an educational approach of active, contextual, cumulative, inter-professional, collaborative, reflective learning, in order to apply new knowledge and skills, not simply recall from memory.

To help with the development of the pilot module, we set up a small number of working groups. A Steering Group is a normal part of any externally-sponsored project and this was no exception, but we also set up four Advisory Groups, chaired by senior members of staff, to consult on specific aspects. These were:

- To review and advise on:
  The Project's working definition of "Education for Sustainable Development in science and engineering"; the main aspects of sustainable development for scientists and engineers (based upon which, case studies can be developed); the professional activities that engineering and science graduates might be asked to undertake (in relation to Sustainability).
- To review and advise on:
  The abilities and skills that would be needed to be developed for the management of the activities (reviewed by Advisory Group 1); case-studies and associated study material for use in the pilot (introductory) course unit.
- To review and advise on:
  Formative and summative assessment of students' progress and achievement; relevant recognition and reward for students' successful participation in the pilot course unit.
- To review and advise on:
  Monitoring the implementation of the pilot course unit; realistic recognition and reward of creativity, and quality of commitment in, educational activities undertaken by academics.

The advisory groups were intended to have a limited lifespan so that the amount of time, that any one individual at a senior level would need to commit, would be small. We also hoped that the setting up of these groups would bring a wider commitment to the ideal and so help to ensure credibility and disseminate the educational approaches.

We felt that a student-centred approach was vital to develop the student skills as well as to underpin knowledge acquisition. To achieve this, students work together in teams of eight. Each of the small groups comprises pairs from each of the contributing study areas, following educational and task-oriented contextual steps. The case studies are intended as 'triggers' in a problem-based approach to learning and reflect the complexity of problems in sustainable development as they impact on the practice of professional science and engineering. Elsewhere [4], we have looked at these as essentially 'wicked' problems. Horst Rittel and Melvin Webber [6] suggest that a wicked problem:

- Has no definitive formulation.
- Has no clear end, no 'stopping rule'.
- Has a solution that is 'good or bad' rather than 'right or wrong'.
- Has no immediate or ultimate test of its resolution.
- Has consequences to every solution, there is no possibility of learning by 'trial and error'.
- Does not have a well-described set of potential solutions.
- Is essentially unique.
- Is a symptom of another problem.
- Has causes with no unique explanation.
- Brings expectations that its 'owner' will find the 'right' answer.

Not all of these have to be present for a problem to be 'wicked', but many global issues, particularly in sustainable development and with a high societal impact, demonstrate many of these features. We are not aspiring to enable the students to master such problems in the course of one brief course unit; however, we can enable students to recognise some of the traits and to seek to remedy them in a collaborative, inter-disciplinary way.

TABLE 1
PROPOSED STUDENT EXERCISES

Title	Aspects	Task
Wheels Change within a company	Sustainability definitions, tools and techniques; Corporate attitudes; Understanding stakeholders' perspectives.	Recommend sustainability initiatives for the company. A consultant's letter provides a list of projects that students may decide to investigate and could choose to include in their plan.
Shelter Change across	Impacts of natural disasters on	Develop a strategy for transitional accommodation

national and cultural boundaries	communities; Stakeholder co-operation; Infrastructure and logistics; Cultural etc differences; Sustainable design.	(housing, schools, clinics, etc) after a natural disaster. Analyse possible alternative approaches and propose a sound and sustainable strategy for their construction. Achieve a realistic and workable balance between international aid and local skills and manpower.
Rules Change driven by regulation	Implementing change via regulation; Impact of environmental regulation; Impact on supply chain: Minimising life cycle impacts.	Review the UK's implementation of three new environmental EU Directives, analysing positive and negative impacts on business, society and the environment. Produce industry guidance, a press release and stakeholder analysis.
Energy Change driven by technological innovation	Implementing change through new technology; Cost-benefit analysis; Barriers to new technology; Infrastructure support for new technologies.	Weigh up the social, financial and environmental impacts of devices such as wind-turbines, solar water heating, geothermal heat pump and photovoltaic cells, through an initial cost-benefit analysis. Understand the implications of introducing new technology to the marketplace.
Shops Change driven by social responsibility pressures	Implementing change through company policy; Supply chain management; Assessing sustainability; Benchmarking.	Assess the current supply chain sustainability; evaluate the company against industry good practice in terms of the supply chain sustainability and develop proposals to ensure approval by the ethical investment community.

Cynthia Mitchell and colleagues [7] suggest that learning how to learn is the single most important goal for sustainable development and that problem-based learning (PBL) naturally lends itself to this situation. However, '[a] shift to PBL may be challenging. Part of this challenge arises from the adjustment required in educators and learners mind-sets… the locus of responsibility for learning rests much more firmly with the student… This represents a challenging shift for teachers of science and engineering, who may be skilled at and derive great satisfaction from the more accustomed practice of delivering "objective" knowledge.' PBL enables students to:

- Practise a logical, analytical approach to unfamiliar situations;
- Activate their existing knowledge;
- Elaborate new knowledge;
- Learn in the context in which knowledge is to be used;
- Learn in an integrated fashion;
- Practise the application of new knowledge;
- Practise critical reasoning;
- Practise critical appraisal;
- Practise self-directed learning;
- Practise different communication skills;
- Practise collaboration in a team;
- Practise reflective learning.

This approach, therefore, was taken to underpin the design of the curriculum and the individual exercises.

The criteria for designing the exercises were:

- The student *role* and *task* are realistic to a young graduate engineer in industry or in an associated organisation.
- The exercise requires the groups to practise professional skills as listed in the unit specification.
- The exercise develops knowledge as listed in the unit specification.
- Problems are open-ended and 'messy' or 'wicked', with no clear-cut answer.
- There is no didactic element – students learn by finding information themselves or, for data not in the public domain, through the facilitators who act as knowledge brokers.
- The exercise tackles sustainability issues that address economic, social and environmental issues holistically, rather than piecemeal.

SELECTING AND DEVELOPING THE FACILITATORS

All of the facilitators are drawn from the ranks of Post-doctoral Research Assistants. A general call was put out to this group of staff, to invite applications to act as facilitator, and the response greatly exceeded expectations. We were keen to select postgraduates who were good listeners, who would be encouraging as regards creative ideas, who would be sensitive to students' concerns and who would be confident enough to cope with any uncertainty in partnering us in this venture. We thought that clear communication skills were very important, especially as so many of our students come from all over the world.

TABLE 2
ROLES OF THE FACILITATOR

Roles and Responsibilities of the Facilitator in Relation to the Students
• Facilitate group process • Facilitate design reasoning and Problem-Based Learning • Act as a resource broker, rather than as a resource • Advise students on relevance and adequacy of learning • Facilitate development of generic competences • Provide case study data (Facilitator Information Sheet) as the need is identified by the group • Be familiar with the case study; ensure material is provided to students at the appropriate time • Attend consistently and ensure start of tutorials as time-tabled

The selection and induction of the facilitators was delivered in four sessions. This started with a general discussion of the process of PBL as a means for the development of abilities and skills in relation to sustainable development in engineering. In the second session the volunteers looked at the activities that the facilitators would set out to support in the three sessions which are assigned to each 'Student Exercise' or case study. They also began to take it in turns to role play what the facilitator would do during the first session of a new Exercise. Three members of the Project team observed the volunteers and their role plays as part of an eventual selection of the eight facilitators who would need to act, not as authoritative didacts, but as supporters of students in their learning. Six of these were to be the main facilitators, with two others available on stand-by, in case of absence. In practice, both have undertaken the facilitation of groups and have also contributed in other ways, notably by vetting some of the material to be used. The third session set out to reinforce what had been discussed in the previous session and to provide opportunities for further role play. The final session examined the content and challenges of the first Exercise to be encountered by the student groups and how the facilitators would help their Group to become familiar with this, perhaps unfamiliar, way of learning. This session also lead to the discussion of how formative and summative assessments would be conducted and the facilitator's role in helping, not judging, the students. It was emphasised that appointment as a facilitator would involve a firm commitment to active participation throughout the first semester in 2007.

In addition to the broad range of disciplines represented amongst those who sought to become facilitators, there was also a considerable diversity of national origins and the final team includes individuals from Canada, Greece, Iran, Italy and Poland, as well as the UK. An even wider diversity was displayed in the student body. This very diversity does make for sensitivity in prescribing global issues for study, but we found that the presence of detailed local knowledge of issues did not give any group particular advantage, because of the need to apply discrimination to the selection of information.

The facilitators will receive a small honorarium as well as a certificate of 'successful participation as facilitator during the Royal Academy of Engineering pilot module'.

The support for the facilitators is primarily their participation in the regular, informal briefing and debriefing sessions, where they meet with members of the Project team to exchange impressions and experiences, as well as observations relating to the members of their group, and to be briefed on the following exercise. This exchange represents a significant opportunity for support and learning from each other and the key points are recorded in writing. These meetings have been both developmental for the facilitators and also a valuable feedback mechanism for the project team. At a mid-point in the programme, the facilitators were also asked to take part in a *nominal group process*. The nominal group technique has been widely used in medical education [8] and has been adapted to wider use, both in medical practice and also in a wider range of educational situations, particularly those concerned with PBL. This is being repeated at the end of the programme, but the interim results indicated that the facilitators viewed the most positive aspects of the pilot unit as being:

- Imaginative, varied tasks.
- Problem based learning.
- Communication skills and group learning.

There were also strong feelings for the multi-disciplinary approach, the encouragement of teamwork and the development of the teaching skills of the facilitators. The less positive aspects included the narrow range of disciplines represented and the role of the two stand-by facilitators. The results show what appears to be a couple of contradictions. Although the multi-disciplinary nature of the groups was identified as a positive, the narrow range of fields from which the students were selected was viewed as a negative aspect of the course. Including students from outside engineering was seen as a major way to improve the course. Another contradiction arises in the feedback and monitoring. It was felt that the students were receiving good feedback regarding the work submitted. It was also felt that the students were ably supported by staff, in that concerns were listened to and dealt with. On the other hand, it was felt by some that the criteria for assessment were not always transparent to students.

RUNNING THE COURSE

The pilot unit was designed for 12 students from each of four disciplines, organised into six teams of eight – two from each discipline in each group, where possible. In the event, the course was heavily oversubscribed and the final group was selected by asking all the potential participants to justify their interest, in writing.

The introductory session featured an explanation of the PBL approach and the role of the facilitators. In addition, the librarian on the project team gave a brief introduction to literature search methods. Each exercise was designed to cover a two-week span with three sessions a week apart. During the first, one-hour, session each group received a 'trigger' for the exercise, which set out the scenario for the issue and the questions to be answered. This was followed by a structured group discussion about what the members of the team had understood, what they needed to know and the questions that they needed to research, both individually and collectively. During the second session, which covered a full two hours, the group members shared the fruits of their collective research, learning from individual 'specialists' who had researched particular topics. This was followed by decisions on how the team would develop and deliver the final report on the issue. The report, or other deliverable, was honed and submitted between the second and third sessions. On an individual level they were also asked to complete a short formative assessment in the form of a Modified Essay Question (MEQ). This involved short answers to questions that require the students to apply the knowledge, which they had just learned, to related issues [9]. The students then compared their answers with an example answer to see where they agree or disagree and where they have thought beyond the exemplar. For the third, one-hour, session the students received the returned report, marked by a specialist academic, and discussed what they had learned. This was both a reflection on the content of the exercise, based on the feedback on the report, and also a reflection on how they have operated as a group and how they could improve their skills. The second hour of this third session then becomes the first session of the next exercise.

MONITORING AND EVALUATION

The nominal group process with the facilitators forms part of the scheme of monitoring and evaluation of the pilot project; a similar, mid-point, process was undertaken with the students. In their case, each of the six groups undertook the process separately. It is intended that the process will be repeated at the end of the course unit, for both students and facilitators. The results from the groups showed some points of unanimity as well as some contrasts. The chief positive points included:

- Multi-disciplinary teams
- Working in groups
- Relevant real-life problems
- Independent learning/learning from others

Less positive aspects included some of the structural issues, eg two-hour session starting at 9am; tight deadlines for written work. Ambivalence was demonstrated with regard to formative assessment of coursework, where some groups were positive about it not counting towards the final marks and others wishing that it did.

One group did not like the number of questionnaires administered and this is probably a reference to another aspect of the evaluation, namely a number of instruments that were to be administered at the beginning and end of the course unit to test whether attitudes had changed. The nominal group process enables the individuals concerned to highlight matters of interest and concern to them, whereas the questionnaire approach focuses on issues that are of pith and moment to the project team.

Three short questionnaires were administered – one in each of the first three weeks – the first being a measure of the students' self-perception of their existing skills, the second a measure of their approaches to learning and the third their readiness for inter-professional learning. The first questionnaire was an internal design, based on questionnaires used for an existing inter-disciplinary module involving Education, Geography and Medicine. The second was based on a questionnaire [10] developed by Noel Entwistle, of the University of Edinburgh, and colleagues and the third on Parsell and Bligh's [11] Readiness for Inter-Professional Learning questionnaire. In the case of the learning and studying questionnaire, we substituted a similar question from Entwistle's ASSIST questionnaire[12] for one that did not relate to the type of learning in this course unit; in the case of the RIPL questionnaire, we modified the language to represent more general inter-professional working than the medical scenario envisaged in the original. At the time of writing, the questionnaires had not been administered for the second time and the analysis is still ongoing.

DISCUSSION

For purely pragmatic reasons the participants were all in their third year. This arose largely because of the timetabling difficulties in trying to organise a common two-hour block across four disciplines: there is a little more flexibility in the third year timetable. We had some discussion about whether it was better for the students to tackle the issues in the first year, as an introduction, or whether the third year option was actually better since by then students had gained some background knowledge that they could bring to bear on the issue. An additional issue was that, by the third year, students had become focussed on marks and assessment and accustomed to a very didactic approach to teaching and learning. During the pilot study we received many comments from students along the lines of 'Why couldn't we learn this way before?'; 'Why can't all our courses be like this?'. What does this say about the ways that universities educate their students? This suggests that it would be better for the development of the students for them to be exposed to these ideas from as early a stage as possible, so that they can begin to take responsibility for their own leaning from a much earlier stage and to develop professional skills and attitudes. One of the ways that we will be exploring to further these ideas is to explore the concept of a 'thread' throughout all three or four years of student progress. This would enable students to develop inter-disciplinary studies, in sustainable development, global citizenship and professional practice, alongside more specifically discipline-based studies. At the same time, we would wish to see whether we could extend the philosophy to a wider range of disciplines

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CONCLUSIONS

The application of a rigorous curriculum design process has been key to the pilot module and underpins the monitoring and evaluation. However, from time to time we have had to take pragmatic decisions that might not always have accorded with strict PBL practice. Indeed, the time taken to design and produce the module has greatly exceeded our expectations. From the feedback from the nominal group process sessions, it is clear that many of our ambitions for the programme are in the process of being realised: the students themselves have recognised and understood the values of teamwork, inter-disciplinary study and student-centred learning. This underpins our initial expectations that the appropriate route for sustainability literacy, whether for engineers or for a wider professional community, is through an inter-disciplinary, problem-based approach. Certainly, the students have found it challenging, not least in terms of 'learning how to learn' [7], while most were in their final year and working towards their final exams.

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