AC 2007-2020: ENVIRONMENTAL SUSTAINABILITY IN UNDERGRADUATE ENGINEERING EDUCATION

William Gaughran, University of Limerick

Dr Bill Gaughran is a Senior Lecturer in the Department of Manufacturing and Operations Engineering at the University of Limerick. He leads a number of research groups, including one in sustainable design and engineering, which includes sustainability strategies for SMEs, waste minimisation in manufacturing, and sustainability in schools and colleges. He is a research partner with the EU INTERREG IIIC/DQE project (Towards a Sustainable Region), and contributes to developing strategies, which inform environmental sustainability policy in EU states. He has developed educational intervention modules for SMEs as well as for engineering and design undergraduates for Interregional EU application. He lectures in design for sustainability across a number of courses in UL, and endeavours to link academic research with industry, through seminars and onsite coaching. He believes that the application of sustainability strategies is not just a moral obligation in manufacturing, but also helps secure competitive advantage. He holds a PhD in Design and Ergonomics from Brunel University.

Stephen Burke, University of Limerick

Stephen Burke graduated from the University of Limerick with a 1st Honours in Technology Education in 2002. He has served for two years as a teaching assistant in UL where he has been involved in the delivery of courses on environmental sustainability and parametric modelling. He is currently in the final stages of completing a research PhD in environmental sustainability strategies for SMEs

Sonya Quinn, University of Limerick

Sonya Quinn graduated with first class honours from the University of Limerick in 2005 in Technology Education. She is currently a researcher in environmental sustainability in the University of Limerick undertaking a Masters by research in the area of sustainability and second level schools in Ireland. Sonya is also a tutor in the Explore Engineering Summer Camp, which is run as an introduction to engineering programme in the University of Limerick and is a consultant tutor in the technology learning centre.

Environmental Sustainability in Undergraduate Engineering Education

Abstract

There is hardly any industry sector in which the management of environmental sustainability is not of significant relevance. It is unfortunate that engineering and cognate areas of education has, for the most part ignored these vital issues. It is therefore, essential that all facets of engineering, design and manufacturing education take action on environmental sustainability concerns through appropriate strategies. This paper describes how, (a) an EU educational intervention has been devised to help promote environmental sustainability in engineering (and other); Small to Medium sized Industries (SMEs), as well as making the tutorials available to university undergraduate programs in selected Universities across the EU, and (b) the design and implementation of an undergraduate module entitled "Design for Environmental Sustainability", in an Irish University. The EU intervention tutorials have been used to provide background support for the module. The module has been devised and implemented in several engineering and cognate programmes, which include engineering, product design, and technology teacher disciplines, to form a mixed cohort of students.

In the context of engineering education this paper discusses the strategies used and the initial impact, of (i) the introductory program intended for SMEs and Universities, and (ii) the introduction and evaluation of the undergraduate environmental sustainability module.

Key words/Phrases: *Environmental Sustainability, pedagogical implications and evaluation.*

1 The EU Interregional modules

The self-paced intervention is a suite of PowerPoint modules, which were designed as a result of collaboration, between four regions of the EU representing industrial development agencies and Universities in each of four countries. These included Ireland, Greece, Germany and Finland. The EU funded research project was entitled Towards a Sustainable Future - Design Quality and Environment (DQE). As part of SME intervention, an intensive study revealed where knowledge deficits existed in SMEs. As a result, it was decided to design a suite of tutorial modules, which would help redress this deficit. Some of the modules, according to the strengths of the Academics involved, would be developed in all four regions and would combine to comprise the complete suite. Figure 1 shows a sample slide, on product life cycle management. All the PowerPoint presentations have appropriate teaching notes, explanations and further references attached. While the tutorials were initially designed for presentation use by expert tutors, it was decided that they could also be used as self-paced tutorials by SME personnel and undergraduate students.

It was decided that these would be tested initially in the home universities of the design team, and would later be made available to other registered EU universities, as well as SMEs. The trials were conducted under a range of agreed criteria, in all of the Universities concerned. Peer evaluation was undertaken first in each of the four EU regions. Resulting from the peer evaluation, design modifications were made to cater for the clarity and accuracy of the material, the achievement of the stated objectives, and to determine how the modules might fit together as well as how they might be sequenced. All the tutorials in Table 1 are in the agreed sequence, with the exception of Tutorial 11 - What is DQE?, as this was compiled after all the others. This tutorial would therefore move to the front (see Table 1)

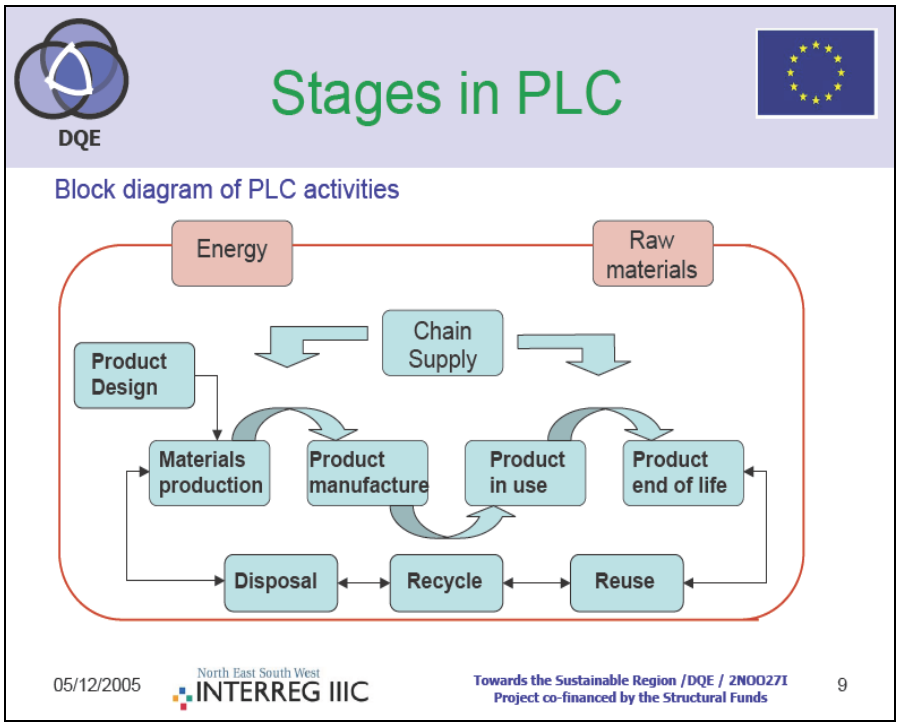


Figure 1 – Typical tutorial slide

Figure 1 above, is from the module entitled Product Life Cycle Management. Each of the modules contains an average of thirty-five slides with accompanying teaching eNotes. As the modules were initially designed for presentation by tutors, it was necessary to add teaching notes to the slides, so that they could provide a fundamental understanding of the areas addressed, in a self-paced/self-teach context. The modules were not designed for an eLearning environment.

Table 1 The Suite of Tutorials.

The Eleven DQE Tutorial Modules	
Tutorial **1:** DQE and Competitive Advantage	Tutorial **7:** DQE based Marketing and customer trend analysis
Tutorial **2:** Environmental sustainability	Tutorial **8:** Integration of management systems 1.
Tutorial **3:** Territorial Issues	Tutorial **9:** Integration of management systems 2.
Tutorial **4:** LCA and management	Tutorial **10:** Strategy: Sustainability through DQE
Tutorial **5:** Design for sustainability	Tutorial **11**: What is DQE?
Tutorial **6:** Concurrent product development	

After the peer interrogation and criticisms the refined modules were further reviewed by potential users. The user group was recruited from the four EU regions involved in the project. Table 2 shows the resulting scores for each module for one of the test centers. Modifications were made on the basis of these scores and on specific recommendations from the evaluators. Some of the evaluators had previous expert knowledge in the areas, while for the others they were induction modules. In Table 2 the evaluators were colour coded, so that they could were not identified.

As may be seen from Table 2, there is a clustering of scores in the good to excellent categories. Where some elements were seen to be poor, these have been corrected. It can also be seen that the third evaluator (Red), for one of the test centres, was more critical of the modules than the others, however this is to be expected in relation to individual differences.

All four evaluators in the centre, found the modules to be interesting and learner friendly, but not entirely suitable for self-paced learning i.e. they found the presentations very good but, full benefit could only be achieved when presented by a tutor. The modules in the suite were not evaluated as eLearning instruments.

Table 2 Evaluation matrix from one centre

	Poor	Satisfactory	Good	Excellent
Material Fits with DQE Aims	- - - -	1,2,3,4 10 2,3,5,6,8,9 3	5,6,7,10 3,6 1,4,7,10 1,5,6,7,8,9,10	8,9,11 1,2,4,5,7,8,9,11 11 2,4,11
Appropriateness of Objectives	- - - -	11 10 2,3,5,6,8,9 10	1,2,3,4,6,7,8,9 1,3,6,10 1,4,10 2,3,8,9,11	5,10 2,4,5,7,8,9,11 11,7 1,2,4,5,6
Are Learning Outcomes clear?	8,11 - 5,6 -	3,7,9 - 3,8,9 9,10	5 1,3,6,10 1,2,10,11 1,2,3,4,6,8,11	1,2,4,6,10 2,4,5,7,8,9,11 4,7 5,7
Is the level pitched appropriately?	- - - -	3 - 1,3,5,6,8,9 9,10	1,4,5,7,8,10,11 2,3,6,7,9,10 2,7,10 1,3,4,6,7,11	2,6,9 1,4,5,8,11 4 2,5,8
Is the Unit Cohesive?	- - 3,6 -	3,5,8,9 - 2,5,8,10 10	1,2,4,5,7,8,10,11 2,3,6,7,9,10 1,4,7,9 3,8,9,11	6 1,4,5,8,11 11 1,2,4,5,6,7
Is the Unit Fluent?	- - 3,6 -	3,8,9 - 2,5,8,10,11 8,9,10	2,4,5,7,10,11 2,3,6,7,9,10 1,4,7,9 1,3,5,11	1,6 1,4,5,8,11 2,4,6,7
Volume of Material In the Unit	3 - 8 -	11 2,3,5,7,9 2,3,5,6,8,11 -	1,4,6,8 4,8,10 1,4,7,9,10 1,2,3,6,7,8,10	2,5,7,9,10 6,11 - 4,5,8,9,11
Are the teaching notes effective?	3 - 3,6 3,7,9	11 5 2,5,8,10 6	6,7,10 2,3,7,8,9,10,11 1,7,9 2,10,11	1,2,4,5,8,9 1,4,6 4,11 1,4,5,8
Additional reference material	3,11 - 3,11 3	4 3,10 - 2,6,9	1,5,6,8,9 2,4,6,8,9,11 1,2,5,6,7,8,10 1,4,5,7,11	2,7,10 1,5,7 4,9 8,10
Quality of Individual Slides	- - 5,6 -	9 - 1,3,8 8	1,2,3,4,5,7,8,9,10,11 2,3,5,7,10,11 7,9,10,11 1,3,5,7,9,10	6 1,4,6,8 2,4 2,4,6,11
Overall Quality of the Unit	- - 6 -	3,11 - 3,5,8 3	1,2,4,6,7,8,9,10 2,3,6,7,9,10 1,7,9,10,11 2,7,8,10	- 1,4,5,8,11 2,4 1,4,5,6,9,11

Just over half the tutorial units were applicable to sustainability in the context of engineering, technology, product design, manufacturing undergraduates. These tutorials were made available on the public folders of the entire campus communities in the participating EU Universities. They were also used as support material for the taught undergraduate module on *Design for Environmental Sustainability,* which will be discussed in part 2 of the paper.

One unit 'Territorial Issues' (3), appears too often in the poor/satisfactory score categories, and this needed some reworking. This was not because this unit lacked quality, but because of its complexity. It addresses the implementation strategies in the context of regional legislation, policy, and culture, which can vary considerably between the EU regions. The teaching/explanatory notes were found to be quite beneficial, but for some module these notes needed to be expanded. Overall the modules received very positive evaluations, across the

four EU regions. These will shortly be made available to SMEs and Universities who wish to avail of them across the EU, along with the other elements of the project.

2 The Undergraduate Teaching Module

2.1 Rationale and Module Aims/Objectives

The module "Design for Environmental Sustainability" was initially designed for a cohort of product design and technology undergraduates. While the issues relating to environmental sustainability were to some extent permeating a number of the taught modules on the course, it was felt that as its importance grew it merited a full and separate module. This would allow students to explore in greater depth the issues relating to sustainability. In the process of moving through the academic structures, within the University, a number of other Course Directors felt that this module would be of particular benefit to their students. As a result four additional programs, with the agreement of their Course teams, requested to be included in the teaching of the module. These included an engineering science course, two courses in technology education and a new course in enterprise engineering, all in addition to the initial product design and technology cohort. The delivery of the course was designed to take these variations into account. The complete cohort would benefit from the generic lecture series (two per week), and the follow-on tutorials would address specific applications and concerns, and specialisms of the sub-groups. The specific interests of the different groups would also find expression through module assignments. The aims and objectives were as follows:

Aims:

- To provide students with an understanding and of how the principles of sustainability must be considered at all stages of design activity, production processes, and throughout the life cycle of any product.
- To encourage creativity and innovation in the context of design for sustainability (DfS), as well as creative problem solving, and to apply 'first principles' strategies to design problem definitions and solutions – whether product or process based.

Objectives:

- To familiarise students with issues relating to energy consumption, resource depletion and waste generation and management, as well as obsolescence, 'disposables', and over-consumption.
- To equip students with appropriate environmental assessment and analysis tools and with the ability to critically appraise contemporary trends and practices in design and engineering.
- To equip students with abilities to perform environmental evaluations on products (streamlined life-cycle analysis – LCA) and processes.
- To outline relevant legislative requirements relating to environmental aspects of products, processes and waste management.
- To provide an understanding of how sustainable design considerations and strategies must be inherent at the concept design stages of a product, as well as throughout its' life-cycle.

Learning Outcomes

Students will be able to:

- Explain the impacts of products and processes in the context of sustainability.

- Display an understanding of issues relating to sustainable design and production practices.
- Use evaluation tools relating to design and manufacture of sustainable products.
- Produce a core study report on the environmental sustainability of a selected product.
- Explain the role of the designer/engineer in sustainable practices and development
- Reflect through prescribed project activity, an understanding of materials selection, processes, embodied energy, waste minimisation, reuse, and recycling.

The syllabus for the module endeavourd to broadly address the principle issues of environmental sustainability.

2.2 The Syllabus

Fossil fuels and global warming/climate change; the environmental, social and economic impacts of materials and processes; land use and environmental impact; ecological foot-printing; optimisation of the lifetime of products – shifting towards a cradle-to-cradle concept, combined with a Product Lifecycle Analysis (PLA); packaging design and analysis; redesign and reengineering to minimise materials, weight, parts and fasteners; transport, distribution and reverse logistics; renewable materials and energy, repair, reuse and recycling; the 'triple bottom line' and sustainability stakeholders; materials selection for sustainability.

Irish Legislation covering packaging, extended producer responsibility, waste, and EU directives covering, accumulators, waste electrical and electronic equipment (WEEE), Energy using Products (EuP).

Environmental Management Systems (EMS), product considerations in EMSs, and environmental auditing, all as outlined in the ISO 14000 family of environmental standards. Pedagogic considerations for teaching cohorts.

Case studies in designing, processing, and manufacturing for sustainability.

Table 3 shows the lecture series. For some elements, such as legislation, visiting Lecturers with appropriate expertise were invited. While the material for the tutorials/workshops followed the lecture material topics, the concerns of the subgroups were addressed as required, and assignments were such as to cater for the differing interests. The core elements were common.

Table 3 Lecture Series

Lecture series "Design for Environmental Sustainability	
1. The Earth is One System	11. Design for Disassembly and Reuse
2. Mankind's Impact – Eco foot-printing	12. Sustainability Tools and Instruments
3. Rainforest Ecology	13. Cultivating Sustainability Cultures
4. Climate Change/Global Warming	14. Product Case Studies – Lessons Learned
5. Fossil Energy – Oil and Coal	15. Stake Holders and Behavioural
6. Fossil Energy – Gas and Atomic	16. Environmental Legislation in the EU
7. Fresh Water Sustainability	17. Environmental Legislation in Practice
8. Company Case Studies – Lessons Learned	18. ISO 14001 and Environmental Audits
9. Design for Sustainability 1	19. Manufacturing Made Miniature
10. Design for Sustainability 2	20. Then and Now – reverse Logistics

2.3 Early participant eco-evaluation

In the lead-in to the module it was decided to evaluate the attitudes and eco-literacy of the entire cohort. Earlier research appeared to indicate that age and education are factors in both environmental attitudes and eco-literacy. Towards that end a survey of Second

Level/Secondary Schools (High Schools) students was taken for analysis in relation to eco-literacy. Figure 2 shows the analysis of the attitudinal response for one sample question. Comparing the teacher's response with that of the pupils is interesting, e.g. in the question concerning the consequences of modifying the natural environment (right graph Figure 2), the students are less sure than the teachers. The same graph shows a parallel response until the 'disagree', option separates the groups. There are also distinct separations between the age groups demographic (left graph Figure 2). The survey included 777 students and 65 teachers, from a variety of school types.

The eco-literacy scores for the undergraduates at the beginning of the module demonstrated the low level of general ecological knowledge (Figure 3). Only 2.4 percent scored an A1 (>85%), in this survey, this had risen to 16.3 percent during the last quarter of the module. The term examination would test their knowledge at the end of the module.

The eco-footprint of the undergraduate cohort was calculated as part of a laboratory exercise on eco foot-printing, during their course work. The average footprint recorded for the undergraduates was quite high at 9.65 global hectares (gha), with females in the cohort scoring better (lower) than the males, having an average footprint of 7.39 gha, compared to 9.91 gha recorded for males. The current "fair earth share" is 1.8 global hectares per person; the average Irish footprint is currently greater than 5 global hectares, and for the USA is greater than 9 gha per capita. The participating students were surprised that their footprint was much heavier than the national average. If the student footprint was measured in the universities of the developed world, it might be even greater. During the thirteen weeks of the course they resolved to reduce their footprint as much as practicable. Their eco-footprint was not measured at the conclusion of the module.

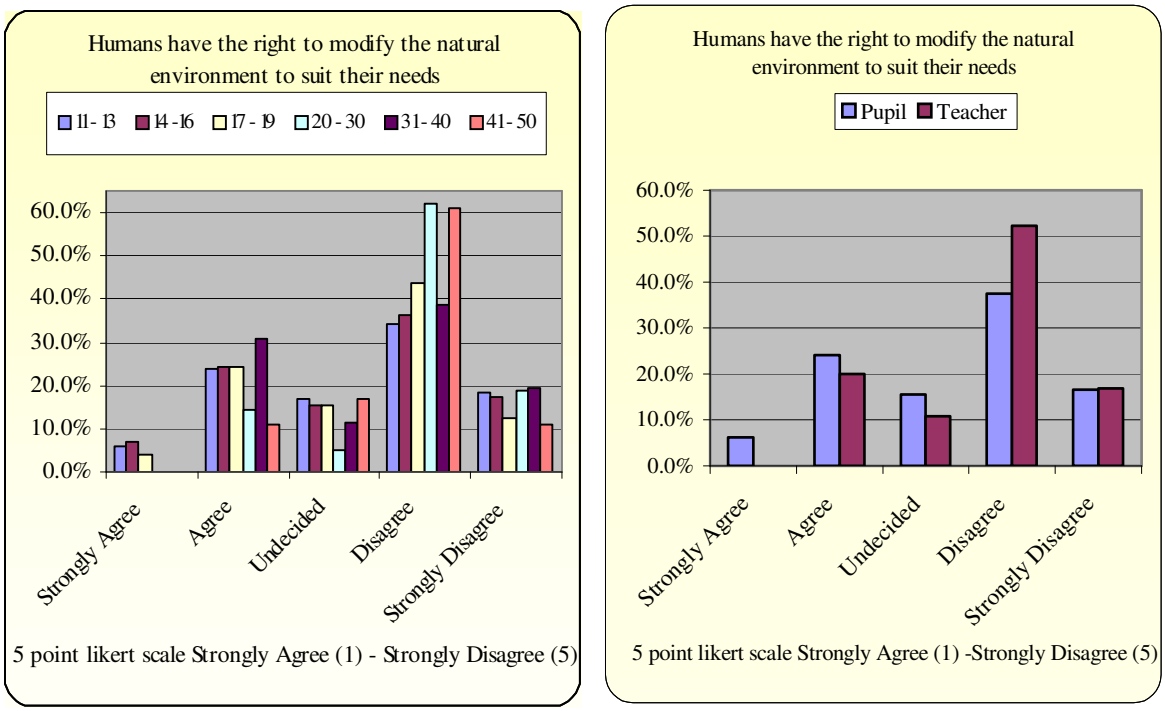
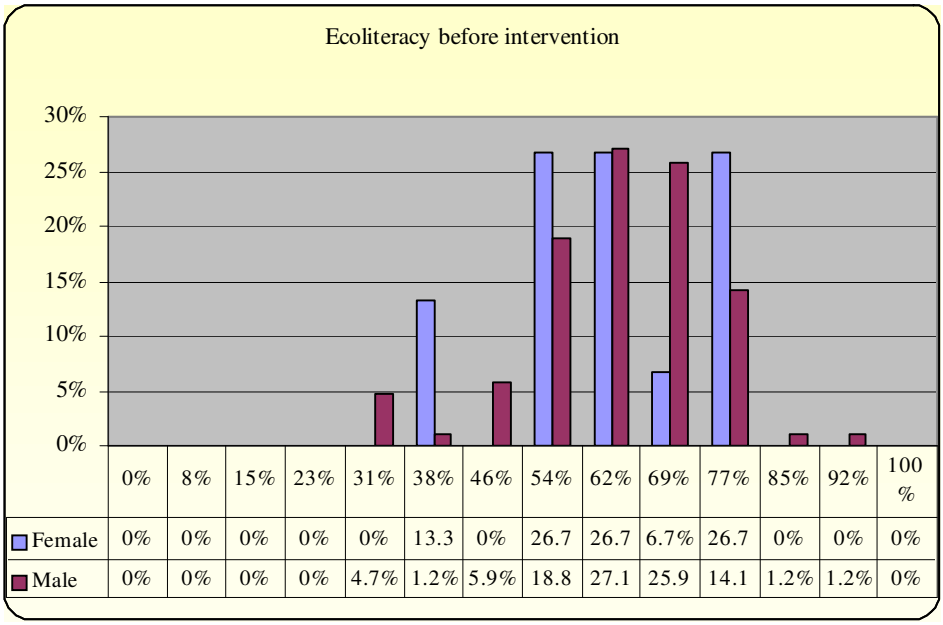


Figure 2 Sample eco-attitudinal questions for Second Level (High School) students



	0%	8%	15%	23%	31%	38%	46%	54%	62%	69%	77%	85%	92%	100 %
Female	0%	0%	0%	0%	0%	13.3	0%	26.7	26.7	6.7%	26.7	0%	0%	0%
Male	0%	0%	0%	0%	4.7%	1.2%	5.9%	18.8	27.1	25.9	14.1	1.2%	1.2%	0%

Figure 3 Eco-literacy test scores for undergraduates at the beginning of the module

2.4 Coursework assignments and evaluation

The evaluation of the module consisted of a terminal test and two coursework assignments, each having a weighting of 25 percent. Course evaluation methodology and assignment specifications were published to the students at the first lecture. The two assignments are seen below, and are timed to follow the appropriate lecture series, all elements of the coursework are compulsory.

Assignment 1: *Weighting 25%* *Submission Friday week 8*

Product Life-Cycle Analysis
Each tutorial group will be given a product to analyse and disassemble in the laboratory. A thorough analysis of the product will be conducted (from packaging to internal components).
Using the tools (LCA software, Checklists, and Analysis strategies), which you have been introduced to in the labs and lectures, perform a life-cycle analysis of the product. From the information gleaned through this analysis you are asked to recommend design changes so as to improve the environmental performance and reduce the ecological impact of the product over its entire lifecycle.

Deliverables:

- Results from the LCA studies
- Analysis of the LCA findings
- Your design recommendations outlined and discussed
- *Sketches, graphs and charts are to accompany the written report and additional support- material should be included in the appendices.*

Note: the report, excluding the appendix should be 2000 to 2500 words.

Assignment 2: *Weighting 25%* *Submission Friday week 12*

Engineering for Sustainability in Manufacturing
You are required to undertake and encompass the following steps and approaches in completing this "Engineering Sustainability in Manufacturing" project.

- Select a real or fictitious company (not less than 50 employees) of your choice and devise an Environmental Policy, which will be used in obtaining ISO 14001 certification.
- Identify the main *acts of legislation,* which come into effect as a result of the company and its activities, and give a description as to why each act is mandatory with respect to each activity.
- Choose *one* product that the company manufactures, outline all of the processes involved, and complete a *process map* for each process.
- Prepare and detail all aspects, steps and approaches of a complete company audit you would carry out to prepare the company for ISO 14001 certification.
- Finally prepare a concise report to be given to top management, outlining all previous information/steps from above, along with suitable and realistic objectives, targets and an ISO 14001 time plan with appropriate milestones and outcomes.

The examination
The examination was divided in two parts. Part one was compulsory and was designed to examine the students across the module, so as to allow them to demonstrate their understanding of the broader issues, practices, and strategies. This part had sixteen sub-elements, and students had to attempt twelve. Each of these elements could be answered in bullet-point and/or essay format, and about 200 words were required to discuss each topic. The answer should express/describe the principle elements for consideration. Examples of the topics for discussion in the 'short answer' questions were:

- Peak Oil, Rainforests, Embodied Energy, The Greenhouse Effect, etc.

There were five in-depth questions, of which students could answer any two, and all questions carried equal marks. In outline the topics included were: life cycle assessment process mapping for a given product, suggested design improvements and alternative ways of meeting customer requirements; establishing a sustainability structure in an Irish second level school, including sequencing, training and deliverables for staff and students; outline the environmental review and audit of a small company incorporating a timescale for your audit and "an improvement strategy" for the company; replacing products with Combined Product Service Systems; discuss the push and pull factors associated with implementing the ISO 14001 standard. Figure 4 shows the overall grades for the Module.

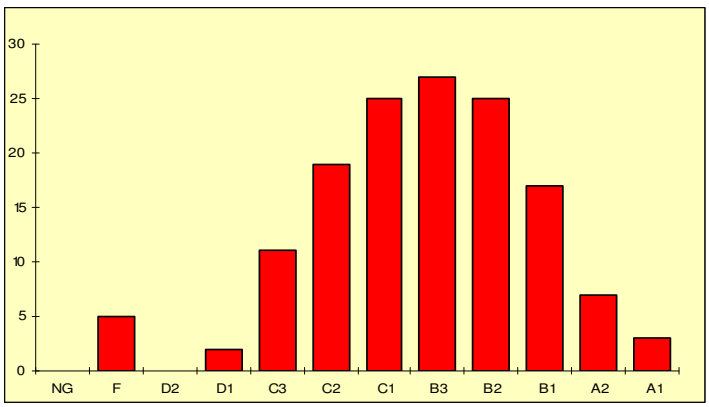


Figure 4 – the spread of grades in the environmental sustainability Module

3 Student progress

In the coursework assignments the students achieved a 'B' average; some of the project responses were excellent to the level of 'exemplary'. The overall grades for the Module were quite satisfactory, with 7 percent awarded an A grade, and 58 percent receiving a B3 or above. The average QCA (quality credit average) score was 2.7 (A1 has a QCA of 4). Of the 5 F grades (fail), 3 did not complete the Module, and 2 were I graded (illness) for the examination and can re-sit in the Autumn. The students are now in a position to make informed decisions on ecological and environmental issues. This applies to whichever discipline the students belong. The popularity/importance/impact of this area of study was such that many of the participants are opting to explore sustainability topics further, through major final year projects. These projects can have a weighting of between two and eight modules. The latter being the weighting for the product design and technology cohort, i.e. two-thirds of the final year marks.

4 Discussion

It is imperative that this area of study is incorporated into all engineering and cognate areas of education. If we speak of corporate responsibility relating to environmental sustainability in industry, how much more so this applies to the education of our future engineers, product designers and technology teachers. It is recognized that eighty percent of the impact on energy usage, and product life cycle, is decided upon at the design stage of a product. Can we influence eighty percent of the sustainability activities in the design of engineering and other courses? Regarding 'technologies' teachers, who will influence young people from twelve years old through their teen years, can educational intervention such as described in this paper be the spark that ignites the fire of enthusiasm, responsibility, and creative and innovative responses to environmental sustainability issues? These young people are the ones who will design energy saving and recyclable products, who will engineer the alternative energy solutions, demand eco-friendly materials and influence the young 'tenants' of spaceship earth in developing a sustainability culture. It is both a responsibility and a privilege for all those involved in engineering education to allow these issues to permeate their teaching. While this may be seen as an enormous task, each individual can do their part, as in the spirit of the Chinese proverb: *"it is better to light a candle than to sit and curse the dark"*

At the University of Limerick, further sustainability modules are being devised, and a Masters course in sustainable engineering and management, is under consideration in the Faculty of Engineering, in collaboration with the Science and Business Faculties. The DQE initiative is being extended to become dqE, with the emphasis on environmental issues, and EU funding is being sought to continue the work with SMEs and Universities for a further three years.

References

1. United Nations, UN documentation centre (2007) *Report of the World Commission on Environment and Development* [online] available: http://www.un.org/documents/ga/res/42/ares42-187.htm [15 January 2007]
2. Living Planet Report 2006 WWF
3. The University of Limerick Prospectus and current Syllabi 2006/07
4. ISO 14001, 2004 Environmental Management Systems
5. The EU Interregional IIIC DQE draft report Oct. 2006