Education for sustainable production: teaching methods for incorporating life cycle thinking into product design and engineering.

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ABSTRACT.

For society to make the shift to sustainable production and consumption, it will be necessary to equip product designers with the appropriate skills in sustainability. This paper makes an initial assessment of an Erasmus funded collaborative teaching and learning project undertaken during 2006, by the University of Brighton and five EU partner institutions (Universities of Bacau, Petru Maior and Brasov (Romania), Technological Educational Institution Athens (Greece), and Tallin (Estonia)) to produce a suite of environmental teaching modules. Each institution brought specific expertise to the project ranging from sustainability to product design. The module developed by the University of Brighton aims to introduce life cycle (LCA) thinking and demonstrate how it can be incorporated into product design and intends to furnish students with the tools to incorporate appropriate environmental mitigation measures into the design process. It was important within the module to provide students from a variety of subject backgrounds with a fundamental understanding of environmental issue. The following components were included:

- Use of a staged process to introduce the concept of Life Cycle Assessment (LCA) by using the actual steps of a product's life cycle as the key learning stages.
- Introduction of the concept of other environmental benchmarking/ indicator tools (e.g. eco-rucksacks) which may be more suited to certain product design applications than a comprehensive LCA.
- Use of problem based learning through the design and subsequent re-design of a kettle after the introduction of each life cycle stage.

It was also considered important to place the teaching within a context wider than the system boundaries of the LCA process as defined by the ISO standards. Subsequently, towards the end of the module, the holistic approach of 'cradle to cradle' design and intelligent materials pooling was introduced to foster an environmentally conscious design philosophy. An evaluation of the course was undertaken after its first delivery which included, in part, a survey of student's environmental opinions before and after the course. The results of the evaluation and scope for further improvement on delivery and engagement of students from non-environmental disciplines is discussed.

1. INTRODUCTION TO MODULE: ETHOS & STRUCTURE & CONTENT.

The development of the module 'Understanding Environmental Life Cycle Analysis (LCA) in a Product Design Context' began in April 2006 as a collaborative effort between researchers in within the School of the Environment and the Design Pathways course leader at the University of Brighton. The module was delivered in December 2006 on a trial basis as an intensive module to second year undergraduate students from the following disciplines: Product Design, Design Technology and Sports Technology. The main component of the

taught module was a substantial course book (approximately three hundred pages), and accompanying PowerPoint series delivered by the course tutor, Kath Shaw. An initial module design which, (after a general introduction to environmental issues), focused on different environmental assessment tools was restructured to allow the course book and matching taught sections to follow the components of an LCA assessment. This structure is shown in Figure 1. The intention of the revised structure was to develop a clear progression of environmental thought to the students and subtly introduce LCA as the broadly accepted most comprehensive way of assessing a product's environmental impacts. The staged process, which examined one specific issue per chapter e.g. raw material production, transport, product use etc, allowed a simple and familiar product (a kettle) to be the subject of a component function analysis and to be discussed and re-designed after new knowledge about each life cycle stage had been gained by the students.

Considering the wide variety of the student's background within the degree courses eligible to study this module and the range of design interests within the student body it was necessary to find a careful balance. Of paramount importance was information which did not presuppose any comprehensive understanding of environmental issues was paramount. A significant element of the course book's introductory chapter was dedicated to explaining the carbon cycle as a biogeochemical cycle and how both materials and energy extracted from the natural balance of this cycle are implicated in climate change. The diverse interests of the students were catered for by providing extensive references for further reading within the course book. Students were also provided with copies of accompanying PowerPoint presentations to aid constructive note-taking. The module document contained all the staged instructions for the coursework assignment and supplementary exercises, which if not covered in class, could be covered in the student's own time. One of the first pieces of information imparted to students was that they would not be expected to be able to conduct a full LCA assessment on a product by the end of the course, but more importantly to be able to appreciate the process and understand the variety of issues involved. A separate handout giving a annotated 'walkthrough' of a full LCA assessment using specialist software (SimaPro) of a coffee machine (so encompassing many of the same issues as the kettle the students were designing) was introduced during Chapter 7.

The simple example product (the kettle) discussed earlier was also the subject of the assessed coursework attached to the module and the way in which the coursework was introduced (stage by stage following the chapters in the course book) was intended to promote engagement with the reflective learning cycle (Kolb, 1984) shown in Figure 2. The iterative nature of the coursework intended to help the students understand the sometimes competing elements within an LCA, for example the production energy of one material for the kettle housing may be lower than an alternative material, but retain the heat in boiled water for a shorter period than an alternative material with a higher production energy and to make an informed judgement or design alteration. The structure of the assessed coursework assignment in relation to the module content is shown in Figure 3 , demonstrating the need to engage with each element of the module in order to progress with the problem based learning assignment. A number of supplementary un-assessed exercises were also included in the module which illustrated particular points such as transport energy.

1. Introduction
Covering basic environmental issues, fuel and material sources, the impacts of climate change and making the initial link between resources, products, and impacts. Case Studies: Concrete & DDT.

2. Material production, use of raw materials
Covering sourcing and production energy & emissions of basic material types; ceramics & glasses, metals & alloys, polymers & elastomers, hybrids & composites. Case study on materials & toxicity: PCBs.

3. Product manufacture
Covering material shaping and assembly methods & energy / emissions in same materials groups as Chapter 2.

4. Transport
Covering the influences of different disciplines involved in assessing transportation issues: logistics, supply chain management, economics, geography, environmental science. Also covers the main logistical and environmental impacts of transport by type; sea, road, rail, air and the importance of transport at different stages in the products life cycle. Importance of packaging. Case Studies of Exxon Valdeez oil spill and Transco National Logistics.

5. Product Use
Covering the designers influence on the impact of products using two main worked examples. Firstly, a car for the introduction to concept of tonnes of carbon dioxide and secondly a kettle for the influences choices of housing material, element and switch). Also introduces concept of scaled up impact over course of products lifetime.

6. Product end of life
Covering waste hierarchy concept, and the possibilities presented by some common materials. Also covers information on disposal options such as landfill and energy from waste (incineration), biodegradable materials. Case studies on plastic bags and packaging.

7. Life Cycle Assessment
Covering the main stages and procedures in a comprehensive LCA assessment as outlined by the ISO 14040 series. Case Studies of cardboard box and rock crusher.

8. Environmental Assessment Tools
Covering other tools which may be more appropriate for product designers where a full LCA is not appropriate or possible: EcoDesign Web, Ecological Footprinting, Ecological Rucksacks, Material Intensity per Unit of Service. Also introduces holistic 'Cradle to Cradle' thinking of Braungart & McDonough. Case Studies of The Durabook & Mirra Chair.

Fig. 1: Module structure & overview.

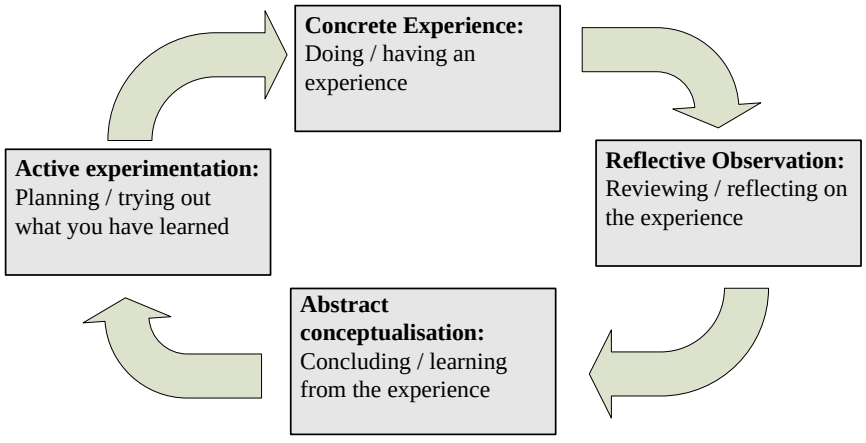

Fig. 2: The learning cycle (Kolb 1984).

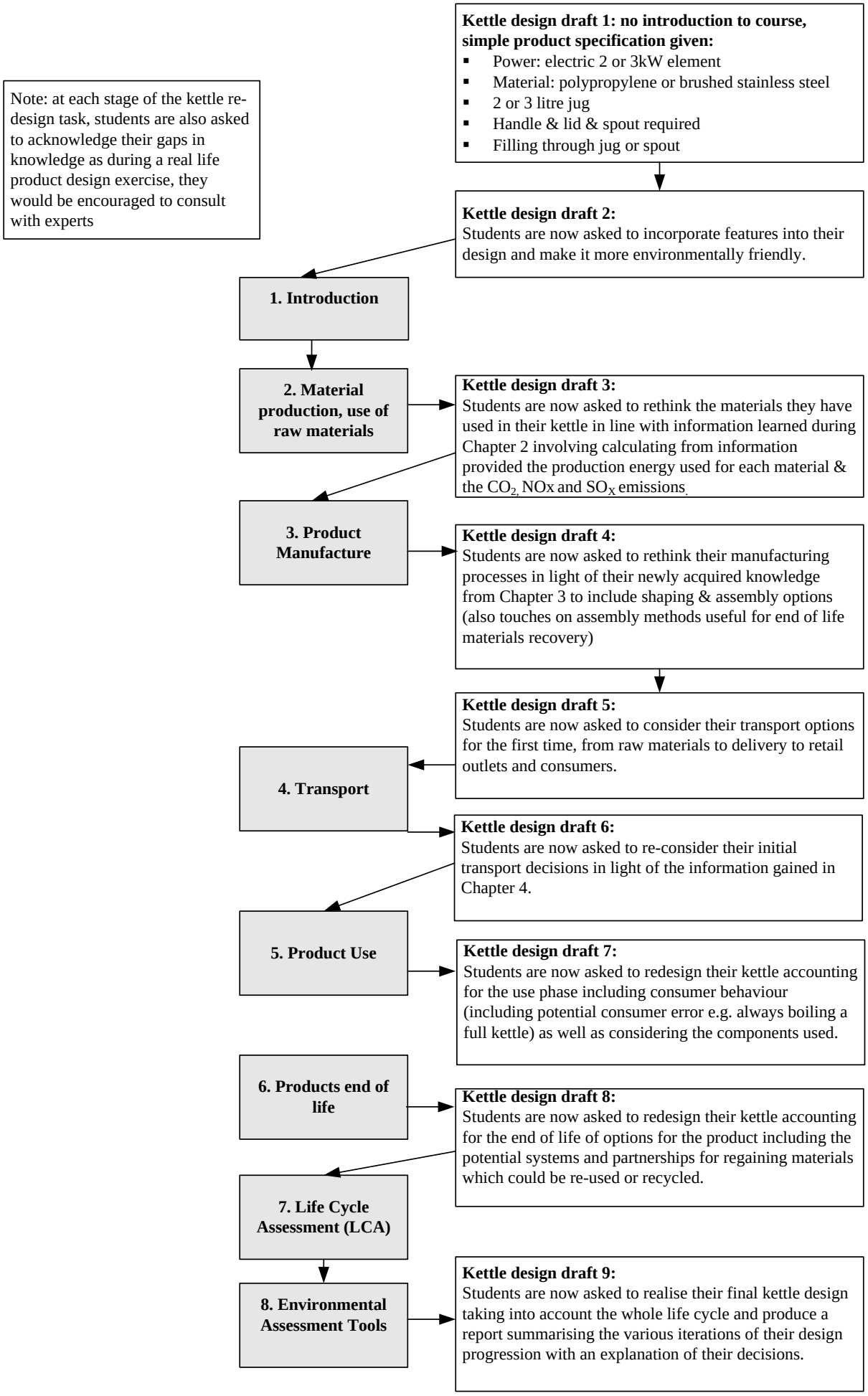

Fig. 1: Kettle design exercise progression.

2. STUDENT COURSEWORK OUTCOMES.

The coursework submitted as a result of the module had the normal variance in quality. There were examples of clear iterative design progression by the students. Design features ranged from simple (simply reducing capacity) to high tech solutions such as materials changing colour in accordance with the temperature of the water inside and multi-sensory alarms sounding when the kettle is filled with more water than required. Some interesting quotations from the coursework provide us with an insight to the student's experience of the module.

One student appreciated the staged process and inclusion of the 'hidden' life cycle stages:

> 'Throughout the project I have gained valuable knowledge of how to design products to be more effective and less damaging to the environment, before this it was difficult to see how transport and materials sourcing affected my design but now I have an understanding of the entire process right from the ground up. My design has changed dramatically from the beginning as I have learnt about each section of the full design process, key to change is the reduction of parts and simplification of the design.'

Another student appreciated the course book as a resource but acknowledged the learning cycle would require some time to fully incorporate LCA thinking into future designs:

> 'The layout of the task and information was easy to follow and informative and at each stage something new was learnt or something that was overlooked was highlighted. While being beneficial more time is needed in order for some of these aspects to become second nature when designing.'

3. STUDENT OPINIONS TOWARDS ENVIRONMENTAL ISSUES & MODULE.

A survey of the students' opinions on the environment and their role as product designers was undertaken, with a questionnaire being completed at both the start and the finish of the module. The opportunity to evaluate the impact of the module was used partly as an exercise to further improve the module after its first delivery and also to examine the impact the module may have on students who have not previously been asked to consider environmental aspects as an integral part of their design, or undertaken courses to equip them with the skills to do so. The questionnaire was based in part on Simpson's (1998) general environmental attitude survey (questions 1-10) and was supplemented with additional questions relating to product design and the environment (questions 11-15).

Thirty two questionnaires were completed at the beginning of the module, and eleven at the end. Although it is unfortunate that the number of responses gained at the end of the module was lower than that at the beginning, and that it was naturally the more engaged (and possibly more environmentally interested students which took the time to complete the questionnaire), the comparison of the changes in attitudes of students apparent from the analysed data and possible reasons for this change are still interesting to discuss.

The questions asked by the survey and the results of the data analysis are shown in Table 1, where some distinct trends can be seen. Responses which drew 25% or over of the answers from the population undertaking the survey have been highlighted in grey and percentage changes in opinion of 10% or more between the first and second surveys have been highlighted in grey with a bold border.

Table 1: Comparison of questionnaire results from beginning & end of module.

responses drawing 25% or over of answers
% change from beginning to end of course of 10% or over

Question	initial survey %	end of course survey %	% change +/-
1. Our environment is			
A. in good shape	0.00	0.00	0.00
B. in some trouble but can be saved with a little effort	3.13	0.00	-3.13
C. in bad shape but a lot of effort might save it	84.38	100.00	15.63
D. in such bad shape little can be done about it	12.50	0.00	-12.50
2. Which of the following do you feel is the most serious environmental problem facing the planet?			
A. ozone depletion	12.50	30.00	17.50
B. toxic waste	0.00	0.00	0.00
C. global warming	78.13	70.00	-8.13
D. water pollution	0.00	0.00	0.00
E. air pollution	3.13	0.00	-3.13
F. deforestation	6.25	0.00	-6.25
	Note: two students noted 'all' as answer in final survey		
3. Who are the worst polluters?			
A. Industries	34.38	60.00	25.63
B. Governments	18.75	10.00	-8.75
C. Individual people	46.88	30.00	-16.88
	Note: one student noted 'all' as answer in final survey		
4. Who should be responsible for making sure we have a healthy environment?			
A. Industry	0.00	11.11	11.11
B. Government	48.28	55.56	7.28
C. Environmental groups	0.00	0.00	0.00
D. Individuals	51.72	33.33	-18.39
	Note: three students noted 'all' as answer in initial survey, and one in end survey		
5. Is the current concern about the state of the environment justified? (Do you think it's really as bad as some people say it is?			
A. Yes	90.63	100.00	9.38
B. No	9.38	0.00	-9.38
6. How would you describe the future of our environment given the current concern?			
A. bright and hopeful	3.13	0.00	-3.13
B. challenging	50.00	63.64	13.64
C. depressing	31.25	27.27	-3.98
D. uncertain	15.63	9.09	-6.53
7. The single most important thing that will make sure the environment is healthy for future generations is if:			
A. the polluting industries shut down, even if people lose their jobs	3.13	0.00	-3.13
B. New technologies can be found to solve our problems	28.13	45.45	17.33
C. People learn to live with less and be more efficient users of energy and materials	43.75	54.55	10.80
D. We find a way to have economic development continue in a way that minimizes pollution.	25.00	0.00	-25.00

8. I believe my health has already been affected by pollution

A.Yes	37.50	27.27	-10.23
B. No	9.38	0.00	-9.38
C. Probably, but I don't know about it	37.50	72.73	35.23
D. Maybe, but I don't know about it	15.63	0.00	-15.63

9. In 20 years time, the environment will be:

A. Back to its normal equilibrium	0.00	0.00	0.00
B. Destroyed / beyond repair	12.50	9.09	-3.41
C. Better than it is now	0.00	9.09	9.09
D. Worse than it is now	71.88	63.64	-8.24
E. About the same as it is now	15.63	18.18	2.56

10. Sustainable development means

A. Development that provides the most jobs	0.00	0.00	0.00
B. Development that will save the environment even if it means lots of people will lose their jobs	0.00	0.00	0.00
C. Development which takes into consideration the economic and environmental needs of future generations.	100.00	100.00	0.00

11. As someone involved in product design I would rate the influence I can have on the environmental burden of one of my products as being:

A/ Very high	15.63	18.18	2.56
B/ High	31.25	27.27	-3.98
C/ Fair	28.13	27.27	-0.85
C/ Limited by my knowledge of environmental issues/ parameters	18.75	9.09	-9.66
D/ Limited by other factors: please state……	3.13	18.18	15.06
E/ No influence	3.13	0.00	-3.13

resons in initial survey:
1. the demand from the public for sustainable and environmentally friendly products / availability of suitable alternative materials
2. people not listening - possibly due to economic issues

reasons in final survey
limited by willingness of employer/manufacturer to co-operate

12. Divide 100% between the following design criteria considerations to reflect how important you think each one is,

	average initial sur	**average end survey**	**% change**
Environmental	34.93	46.33	11.41
Economical	30.24	32.33	2.09
Engineering	34.77	31.33	-3.44

* Question 13 was a question about the respondents favourite product (with reasons, not necessarily environmental)
only two products were given in responses as having environmental reasons and the same products (bicycle & i-pod appeared in both the initial and end of course surveys

14. On a scale of 1-10 (1 being not at all, and 10 being completely) how do you feel your position on the environment has changed as a result of what you have learnt in this course?

average	**median**	**mode**
5.36	5.00	5.00

15. Do you think this course will help you with your future product designs?

yes	**no**	**unsure**
81.00	9.00	9.00

In response to question 1, almost overwhelmingly (84%) of students believed that 'the environment was in bad shape, but a lot of effort might save it', which increased to 100% in the second survey. Global warming was seen as the most serious environmental problem facing the planet in both the initial and resultant surveys. Considering the recent daily infiltration of the issue to the mainstream news and the publication of the Stern Report immediately before the course began, this result is perhaps not surprising. In question 5, students were adamant (bar one response) that the current state of concern over the environment was justified which may also support the recent assertion (IPPC 2007) that the scepticism which has surrounded the debate for many years has been replaced by consensus. Students were 100% agreed from start to finish on the meaning of sustainable development, possibly again reflecting the permeation of the concept into society in recent years.

The questions relating to environmental responsibility (questions 3 & 4) demonstrated an interesting pattern. In Question 3 respondents felt industries (34% of vote) and individual people (47% of vote) were the worst polluters instead of Governments. However, the option to answer of 'Governments' might have been avoided by respondents as it may have been seen as an indirect polluter. Opinions had swung by the end of the module with a 25% increase in respondents feeling industries were the worst polluters, and a negative swing of 18% away from individuals. The emphasis within the module on explaining the environmental significance of the extraction and processing of raw materials and the ability of the product designer to silently influence consumer behaviour and consumer error (e.g. overfilling a kettle) may have influenced the shift somewhat. In question 4 there was an associated shift away from responsibility for a healthy environment away from individuals (top answer at the initial survey) to the Government as the top answer by the end of the module. A number of individuals responded to questions 3 and 4 by advocating all parties were responsible. This option should be added to the questionnaire if it was to be conducted again in the future.

Despite the level of concern about the environment expressed in questions 1 and 5, the opinion on whether the future was depressing (falling from 31% of the vote to 27%) or challenging (rising from 50% of the vote to 63%) showed a slight strengthening in opinion over the course of the module towards a challenging future. It is possible that students, having been educated in the methods of assessment available to them to make their products more environmentally sound, felt more equipped to contribute positively towards the future state of the environment even though a new challenge had been presented. Nevertheless, there was an element of the respondents being resigned throughout both surveys that in twenty years time the environment would be worse than it is now (72% of responses during first survey and 64% during second survey). The results of question 14 would support this, falling very much in the middle of the 1-10 scale offered in response to the question of how students felt their position on the environment had changed as a result of undertaking the module.

In response to the question of whether the students thought their health had been affected by pollution, a large increase was seen (from 38% to 72%) in the number of students aligning with the response 'probably, but I don't know about it'. A number of case studies in the course document related to hidden pathways of pollutants such as DDT and PCBs (both bioaccumulants in food chains) and the prevalence of man made chemicals in the environment. This knowledge appeared new to many students, initiating many questions on thresholds and regulations and may have been responsible for the change in opinion by the end of the course.

It appears from question 11 that students were aware from the beginning of the course that they had a 'high' (31%) or 'fair' (28%) influence on the environmental burden of their products and their opinions did not change significantly by the end of the course. The reasons

given by respondents to the statement that their influence was limited by other factors are shown in Table 1. Some of the comments received as a response to question 15 and in the submitted coursework potentially provide more insight into detailed opinions and underlying reasons, and in general support the conclusion that 81% of students felt the course would benefit their future product designs (albeit 81% of only 11 responses). Some of these responses are shown in section 5.

Question 12 possibly provides some of the most interesting results of the survey and shows that by the end of the module there was a significant positive change (11%) in favour of environment in the allocation of 100% by importance between the different design criteria considerations of environment, economics and engineering.

Some interesting quotations from the comments area of the environmental issues survey were collected. The first student hinted at the need for a new design approach being challenging but entirely necessary and the second student felt environmental design was something so specific it would only be fully comprehendible in relation to an independent design project:

> '…very interesting and eye-opening, awareness of the whole subject and not just small areas will help me a lot. It might confuse me when I design a product – lots more to think about!'

> '…too much detail given and will forget information after the coursework submission and I will find out the required environmental details only when designing a product by ourselves.'

Students were also asked to use one of a variety of environmental assessment / eco-design tools covered in Chapter 8 to assess their design in its final format. The majority of the students chose to use an online tool proposed by leading author on Eco-design Professor Wolfgang Wimmer (Wimmer, undated). Responses to this tool (and to the tools suggested in general) were positive as students were previously unaware of their existence.

4. PLANNED IMPROVEMENTS AND CONCLUSIONS.

Initially it was intended that during the intensive module students would be given time in class to work on their coursework kettle designs. However, the entirely new nature of the subject matter to the students and the reactions this fostered led to the structure being altered slightly to allow students to have brief discussions on how they may change their designs during class which they could subsequently think about further in their own time. Was the module to be repeated again, it may be best to opt for the more traditional non-intensive delivery to allow time for the new concepts being introduced to sink in and for design ideas to gradually develop, as some students appeared phased by the pace of the new concept and iterative design process. Supplementary exercises containing calculations may be better set as homework in some instances and short reports being written on the more discursive supplementary exercises to be included in the final coursework report.

Due to the variety of subject matter covered during the course it would be of benefit to invite guest speakers or a wider variety of guest lecturers to cover some of the specialist areas, particularly the production processes and materials science elements. This would also reflect more truly the ethos proposed by the module that in their future design careers the students should feel positively about bringing in advice from specialists / consultants in areas outside their field of expertise. Students seemed somewhat relieved that they were encouraged in their

coursework to identify if they had a gap in knowledge on a particular aspect of design and would ideally like to seek more specialist help in this area.

It is necessary to see the success of the module as a work in progress which will be improved for its next delivery taking into account the experiences described in this paper. Therefore to conclude on the success of the whole module would be premature. However, in general the responses on content were very encouraging although the intensive delivery structure should be rethought where possible.

Potential improvements may include delivery as a final year module where the kettle is used only as an example running throughout the course, with different design options being given for consideration, however, the coursework being set as the design of a product chosen by the individual could prove more stimulating for the more advanced student.

At the beginning of the module students were allowed to examine sample kettles (kindly donated by staff at the University) of many different designs to help develop their thoughts. If workshop time was allocated then students may be able to take these examples apart to further aid their considerations of assembly and ease of dismantlement with materials re-use in mind. Further workshop time allocated for using the CES Eco-selector software (Granta Design Ltd 2006) may also help students independently explore the information available about different materials not given in the course module document and actively see the changes in production / processing energy when they make a material selection choice.

It would also be of benefit to repeat the survey with the next group of students to undertake the module to not only gain a wider dataset but to see if student opinions on the environment are changing over time (i.e. a longitudinal study).

REFERENCES.

Granta Design Ltd (2006) CES EduPack. Granta Design Limited, Cambridge, UK. © Granta Design 2006.

IPPC. (2007) Climate change 2007, the physical science basis. Summary for policy makers. IPCC WG1 Fourth Assessment Report. Available online at http://www.ipcc.ch/SPM2feb07.pdf (accessed February 2007).

Kolb, D.A. (1984) Experimental learning experience as a source of learning and development. New Jersey, Prentice Hall.

Simpson, B. Environmental awareness survey. *Global Issues in Language Education*, 1998, 30 pp12-14 / *Green Teacher Magazine* p.27.

Wimmer, W. (undated) Ecodesign Pilot version 3. Available online at http://www.ecodesign.at/pilot/ONLINE/ENGLISH/INDEX.HTM (accessed November 2006)

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