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Project-based Learning: a Case Study in Sustainable Design*

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Most sustainability problems are system problems (for example, transport or food consumption) and almost insoluble without completely new ways of thinking. To address sustainability issues, which in broad terms are the key issues of our times, designers need to be able to understand design problems in context, envisage and describe better future systems and then design products that could be part of a new improved system.

This paper introduces a framework for the definition of sustainable design projects. The paper then uses this framework to describe the development and delivery of a sustainable design project to second year Product Design students whose programme of study spans the disciplines of engineering, the visual arts, business and psychology. The project was divided into a number of phases. In the first two phases students worked in teams to research and so build up a clear view of the context for a given problem area (for example, mobile phones); they then used this context as the basis for a definition of a vision of the future (10–15 years from now). Finally, each individual student defined a design brief for a product that might be a part of their team's envisaged future and developed designs that satisfied the brief.

In addition to developing design skills and knowledge, the project allowed students to gain first-hand experience of challenges to be addressed in the realization of sustainable products. A key challenge demonstrated through the project was that the future will be about understanding product design in as wide a sense as possible; it is this context, and the derived understanding that comes from design research, that will be key in the future.

Keywords: sustainable design; product design; interdisciplinary teams

INTRODUCTION

'SUSTAINABLE DEVELOPMENT meets the needs of the present without compromising the ability of future generations to meet their own needs' [1]. The achievement of sustainable development requires the consideration of a range of factors covering social, economic and environmental issues. Sustainable design, for the purposes of this paper, is taken to be the design of products (in the form of goods and services) that contribute to, rather than work against, the achievement of sustainable development. The successful delivery of sustainable design requires means by which the sustainability of design alternatives can be evaluated. Strong and Hemphill [2] describe the application of the five capitals approach to the appraisal of a regeneration project in Northern Ireland. The five capitals are illustrated in Fig. 1 against a backdrop of what Strong and Hemphill refer to as the three pillars of sustainable development.

It is well accepted, especially in the design and life-cycle support of large civil and military products, that consideration of life cycle costs and processes during the design of products offers real benefits in terms of reduced life cycle costs [3]. The chart shown in Fig. 2 illustrates the typical mismatch between life cycle costs committed and spent that occurs in many major projects. It can be seen that typically many costs are committed very early in the product life cycle.

Extended to sustainable development, these costs fall into all of the five capitals categories. For example, Hawken, Lovins & Lovins assert that all the really important mistakes are made in the first day, and by the time the design for most human artefacts is completed, 80–90% of their life-cycle economic and ecological costs have already been made inevitable [4].

In their manifesto for 21st century organizations, the MIT 21st Century Manifesto Working Group [5] identify aspirations to achieve organizations that are both environmentally and socially (in societal and personal senses) sustainable. A key to achieving these aspirations lies in the professional development of designers with the capability to consider all three areas of sustainable development as opposed to just the environmental. Through the development of these capabilities, new opportunities will emerge for designers to help solve complex systems issues by the application of sustainable development principles through the entire design lifecycle: from the identification of design problems in a system context through to the delivery of new solutions that fit within the system.

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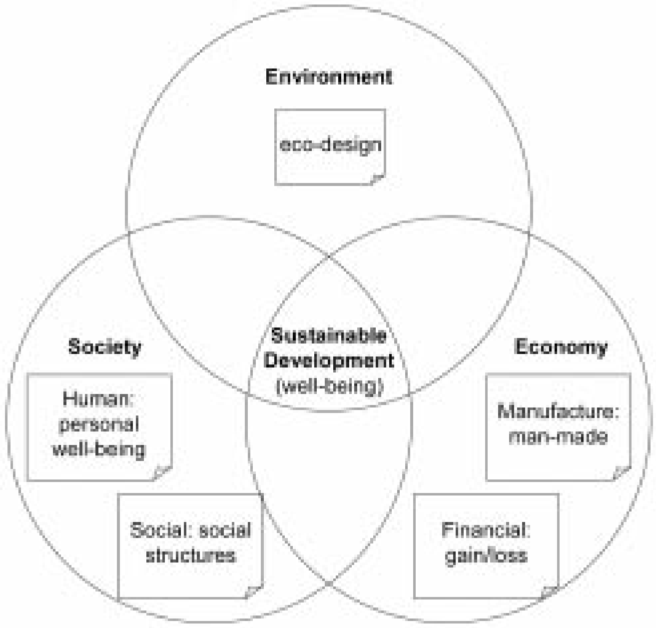

Fig. 1. Five capitals on the three pillars of sustainable development.

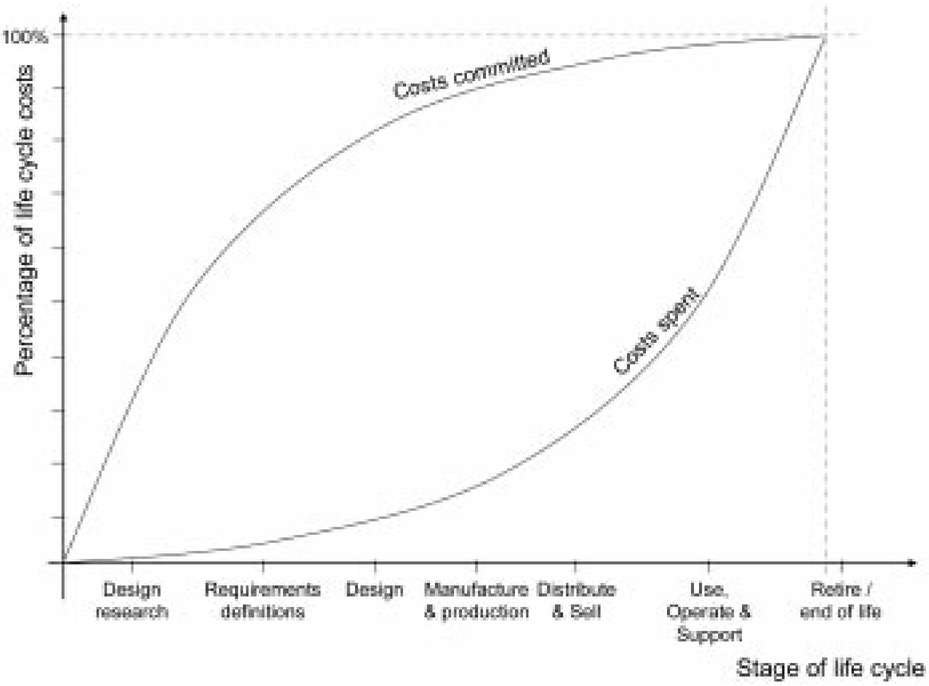

Fig. 2. Schematic of typical mismatch between life costs committed and spent.

THE PROGRAMME OF STUDY

The sustainable design project described in this paper was developed as a part of a Level 2 design studio module in a programme in Product Design that took its first students in September 2003. The programme is novel in that it is led from a faculty of engineering (with core partners from civil, electronic, materials and mechanical engineering) but its content spans both the engineering disciplines (including engineering science and design technology management) and other design related disciplines such as the visual arts, business and psychology. At Levels 1 and 2, the programme balance is one third engineering, one third other design related disciplines and one third design studio. The design studio modules are built around design projects and, at Levels 3 and 4, grow to form one half of the programme.

The design studio modules are the vehicle through which students gain both design skills and design project experience. A decision was made early in the programme development to not enforce a specific design process on students. However a stage gate process that mirrors current industry practice is used as a framework for design projects. The purpose of this process is two-fold:

(1) it gives students experience of the kind of new product definition process (which would typically be a part of a broader product development process) in which they are likely to find themselves working in their future careers;
(2) the stage gates can be used as a framework for the assessment of design project outcomes. The stage gate process that is used is presented in Fig. 3 along with the span of the four projects that formed the Level 2 design studio module.

It can be seen that the stage gate process starts in the investigation of a challenge or new technology and works through design research, the translation of needs into requirements, concept design and design development; all stages, and especially the final two, may involve the creation of both digital and physical prototypes. The decision gates, shown by the diamonds in Fig. 3, are an initial design brief, research results, a requirements definition document, a number of concept designs and a finished product definition. The projects,shown in the oblongs in Fig. 3, give students experience of all steps in the product definition process and cover the range of topics that are identified by Cooper *et al.* as key to the successful delivery of new products [6].

Since each design project has the same weighting, positioning the design projects requires the control of both their extent, in terms of the product definition process stages that are covered, (represented by the lengths of the oblongs in Fig. 3) and the depth of coverage in each stage (represented by the widths of the oblongs in Fig. 3). It can be seen that, in comparison to the other projects that the students completed on the module, the sustainable design project covered all stages of the product definition process up to the end of concept design. The sustainable design project formed one quarter of the Level 2 design studio module and was designed to consume 100 hours of student time.

PROJECT-BASED LEARNING IN DESIGN EDUCATION

The body of knowledge upon which sustainable design practices are built is still in the early stages of its own lifecycle. A key reason why project-based learning was selected for this project lay in the fact that the body of knowledge upon which it is based is young and fast moving. As such there is limited value in a traditional design project approach where students apply what they have learnt to a problem. It is better that students develop strategies, skills and confidence needed to create and maintain their own knowledge bases from the emerging body of knowledge rather than take the role of passive learners. In essence, the project described in this paper provides students with opportunities to engage with information in a problem space. This shift from a traditional emphasis on the content coverage of the project to problem engagement is just one of three issues that Tan identified in changing

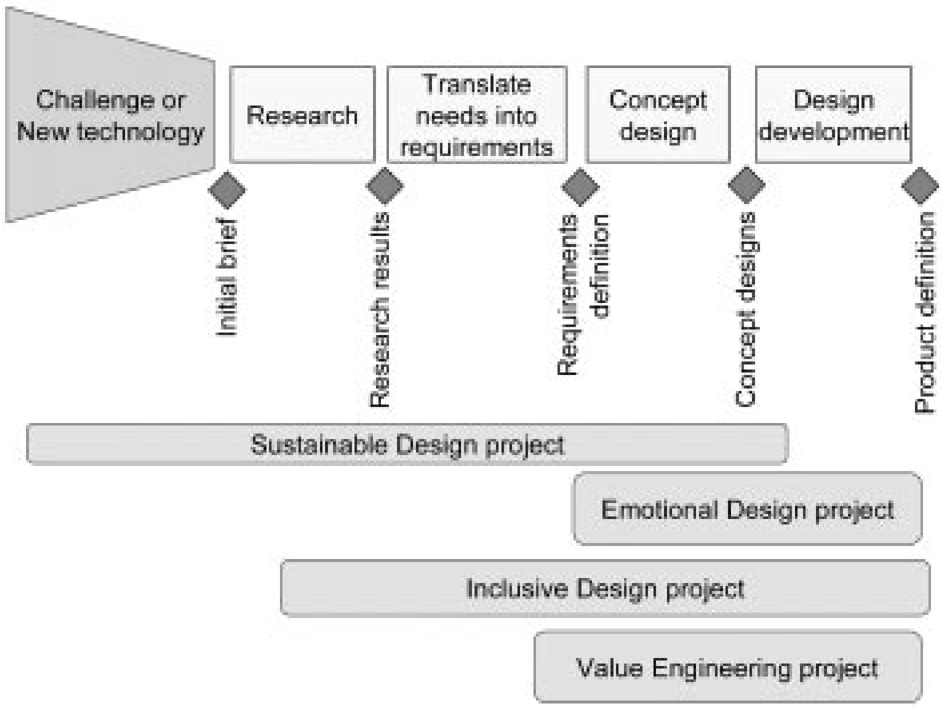

Fig. 3. Product design, product definition process and design projects.

from traditional to project-based learning models; the other two are the role of the lecturer changing to that of coach and the passive learner becoming an active problem-solver [7].

The use of design projects is a well accepted approach to the learning and teaching of engineering design in higher education [8]. However, there are differences between traditional design projects, where students apply knowledge gained in other courses in project work and project-based learning where students gain new knowledge and competencies through the completion of the project. The acquisition of new knowledge and competences was something that the design project described in this paper was deliberately intended to achieve. This is why, at the beginning of the project, students were sent out to explore and understand the context of a given problem area. The new knowledge was shared with both staff and other students on the project through design research presentations at the end of the first phase of the project (see later). Raucent [9] identified a key difference as lying in the way in which projects are assessed—from results focused on traditional design projects to process focused on project-based learning projects.

Yeung *et al.* report evidence from a number of studies, largely in the medical sector, indicating that problem-based learning, as opposed to traditional teaching, is more likely to result in independent learning, long-term retention of knowledge and an ability to integrate basic scientific knowledge into clinical practice [10]. There are clear parallels between this and the integration of knowledge from a range of disciplines into design practice. A number of authors describe the implementation of project-based learning in engineering curricula. Frank *et al.*, for example, describe the implementation of a project-based learning course in a mechanical engineering programme [11]. They highlight a number of benefits including increased student motivation and acquisition of knowledge and skills, but recommend training for students in team-working, and lecturers in facilitation and mentoring skills, if such courses are to reach their full potential. Hansen *et al.* report strategies that have been used to overcome important issues in three broad areas at Aalborg University in Denmark: student motivation, definition and balance of the curriculum, and increased demand for teaching resources [12]. In a project-based learning environment, the definition of projects is important because they form a skeleton that supports and integrates elements of the curriculum. The framework for the definition of sustainable design projects presented in Fig. 4 could be used to contribute to the definition of curricula in sustainable development in that it provides a consistent means of defining the extent of individual and collections of projects.

In summary, the framework has two axes, the starting point of the project and the end point. Each axis has three phases within it:

- *situation* refers to the system within which a given project sits;
- *problem* refers to a problem within the situation that is to be defined and/or addressed by the project;
- *solution* refers to a means of overcoming the problem, so improving the situation.

		Project start point		
		Current situation	Current problem	Current solution
Project end point	New situation			
	New problem			
	New solution			

Fig. 4. Framework for definition of a sustainable design project.

A project can start in one of three places, a current situation, problem or solution. Where a project starts influences what the students will do during the project and what they need to learn. For example, a problem that starts in the current situation is likely to require research at a system level whereas a project starting with a current solution is likely to require detailed analysis of a range of design solutions. Similarly, a project can end in one of three places, a new situation, problem or solution. Where a project ends influences the scale of the project. For example, a project ending with a new situation may require the definition of a new system or way of working and the evaluation of prototype products in this new situation whereas a project ending with a new solution is likely to require the detailed design of a new solution (a product, service or some combination of the two) but not its evaluation in the context of the new situation.

The position of a project in the framework governs its extent. For example, designing a solution to address problems in a situation would require students to analyse the current situation, identify problems associated with the situation, and from these identify design requirements for new solutions which they could then design. In contrast, the redesign of an existing solution may be a far less extensive project, although one that requires more detailed work.

Our project started in a current situation and ended in the definition of a new solution. Students began their project by investigating a current situation, for example, the impact of mobile phones on sustainable development. From problems identified through the analysis of the current situation they envisaged an improved future situation and designed new solutions that could form a part of the new situation.

THE SUSTAINABLE DESIGN PROJECT

The project was one of four that formed the Level 2 design studio module in the Product Design programme. Each project had an allocation of 100 study hours per student; this included both contact time and private study. The project was delivered to 31 students, in three phases over a period of 20 weeks; this included a four week vacation and a two week examination period. The project timetable is given in Table 1. The materials that were provided to the students are given in the Appendix of this paper and referenced from Table 1.

PROJECT DEFINITION

At the beginning of the project, students were asked to state their preferences over four project areas: small domestic products, mobile phones, mobile food and supermarket /out of town shopping (see Fig. 7 for more details). These preferences were used to allocate students to teams; in the event all students were placed in a team related to their first choice problem area. In the first phase of the project (see Fig. 8) students researched their given problem areas in these teams. This enabled them to build up a clear view of the context for their design projects in terms of both the sustainability of existing solutions and social/human aspects of the situations within which these solutions exist. The results of this research were presented through poster presentations in Week 4 to the whole student group.

A key learning point for most, if not all, of the teams was the importance of people's behaviour in the situations that they studied and the span of control that it is feasible for designers to have. To provide students with a basic understanding of issues to be addressed, a seminar on professional responsibility was delivered to students in Week 4. Subjects covered included beliefs, value systems and professional responsibility—extending the notion of professional responsibility to include responsibility for future generations.

In the next two weeks, each student team completed Phase II of the project (see Fig. 9).

This resulted in a team definition of a vision of the future (10–15 years from now) and a set of individual design briefs. In defining their future vision, students were allowed, even encouraged, to change the rules so that a viable future could be possible. For example, students working in the area of supermarket shopping might have assumed that carrier bags are no longer available. The definition of a future vision was a challenging mental task to ask of the students at this stage. However, it provided opportunities for them to see where innovation can start and experience the very early stages of a design process; each individual design brief was for a product that might be a part of their team's envisaged future.

In Phase III of the project students completed individual design projects that delivered designs to meet their individual briefs. This phase included three workshop sessions where students learnt how to use a material selection software package* and consider the environmental impact of material choices. Finally, in Weeks 19 and 20, the design definitions were incorporated into a team poster that encompassed the Phase I research, the team vision, and the individual briefs and resulting designs.

DELIVERY OF LEARNING OUTCOMES

The purpose of the sustainable design project was to contribute to the delivery of the Level 2

* The CES Materials Eco-selector software was used to allow students to evaluate material options in their designs with respect to the environmental impact that each material has through its entire lifecycle. More information on this software package is available from www.grantadesign.com/products/mi/ecoselector.htm.

Table 1. Project timetable.

Week	Contact time	Private study work	Materials provided to students
0	Introduction to Phase I of the project; teams defined		Fig. 6, Fig. 7, Fig. 8
1 2 3	No formal contact Tutorial with personal tutor on documenting meetings as evidence for peer assessment No formal contact	Students teams research their assigned project area and produce posters for presentation in week 4.	
4	The definition of professional responsibility (Dr Simon Robinson, University Chaplaincy) Introduction to Phase II of the SD project—developing a vision and individual briefs	Phase I team poster presentations	Fig. 9
5	No formal contact	Student teams develop team visions Individual students develop design briefs	
6 7 8 9 10	Team meetings with staff to assess team visions and individual briefs Introduction to Phase III Material selection workshop (1/3) Material selection workshop (2/3) Material selection workshop (3/3) No formal contact	Students work on individual designs	Fig. 10
11	Individual progress reviews		Fig. 11
12–17 18	No formal contact No formal contact	Students complete designs	
19	Individual progress reviews with staff	Student teams complete posters	
20 20+	Assessment of individual design portfolio pages and CAD models Assessment of posters		

design studio module objectives. The relevant module objectives and the way in which they were satisfied through the sustainable design project are summarized in Table 2–Table 4. Through these tables, the module objectives are divided into three broad areas: module learning outcomes (only the relevant module learning outcomes to this project are included), integration with other modules (since one of the purposes of the design projects is to provide students with opportunities to integrate learning from a range of disciplines) and design communication skills development.

EXPERIENCES IN DELIVERING THE PROJECT

In delivering the project, a deliberate choice was made to make the students walk through the stages of the process (research, vision, brief) and to feed them the questions at each stage rather that set the whole project out at once. This can be seen in the project schedule where each phase of the project was introduced after the previous phase had been completed. The intention behind this was to encourage the students to take as wide a view as possible to start with so that their understanding of sustainable development was built without closed goals. This helped to ensure that the design work was carried out in a realistic setting.

A summary of the marks awarded for the work that students submitted is given in Table 5. These reflect typical mean marks for design projects and are included to provide an indication of the quality of work submitted at each stage of the project.

It can be seen that the quality of the first work submitted was very high and that it dropped towards the middle of the project and picked up at the end. Initially the students were very enthusiastic about the project and in the early weeks low workload from other modules meant that they were able to devote more time to this project. As the term progressed, however, time pressures from other modules meant that students were able to devote less time to this project. Week 11 was the last week of an 11 week term and the progress shown by the majority of students was low—largely because of deadline pressures from other modules. In future years this session will be kept, to ensure that all students at least have a feasible brief, and progress will be monitored but not assessed. In essence, the purpose of the week 11 progress review will focus on providing support as needed by students and ensuring that all students have a feasible design brief.

Feedback from students gained through a questionnaire on the half of the module that included both the Sustainable Design and Emotional Design projects yielded the comments given in Fig. 5. Only those comments that are associated with the Sustainable Design project are included in Fig. 5.

It can be seen that, overall, the project was well received by students. As is often the case, a number of students would prefer to work only individually. However, the development of team-working skills is widely recognized as being an essential part of most degree programmes and the amount of research that could have been completed would have been significantly reduced if students had been working on an individual basis. One or two teams did experience problems in varying levels of input by team members. This was addressed through the introduction of opportunities for students to provide confidential feedback to the project leader during the project. Students were encouraged to support their comments with evidence in the form of documents of team meetings. Guidance on the creation of such documentation was provided through small group teaching sessions delivered by a number of staff. The briefing materials provided to tutors are given in Fig. 12.

Table 2. Relationship between the project and module objectives.

Relevant module learning outcomes (By the end of this project students should be able to: . . .)	How addressed by the sustainable design project
. . . outline factors influencing the choice of materials and process selection and their importance in design and apply scientific principles to determine the optimum materials and processes of manufacture for a range of existing products and new designs;	Students were taught, through three workshop sessions, how to use material selection software (CES4)[1] to select materials to suit given design applications and with a consideration of their environmental impact.
. . . communicate conceptual and detail design ideas (including tolerance information for manufacturing) by means of sketches, CAD and DTP software with an advanced level of proficiency.	The team poster included conceptual design definitions and was produced using Computer Aided Illustration and Computer Aided Design software packages*. The individual portfolio pages included design developments and were produced using any suitable media—manual, computer-based or a combination of the two.
. . . use and develop frameworks to identify and describe emerging socio-cultural trends, including sustainability, and understand the relevance of such to the designer.	Students created and applied a framework for Sustainable Design based on research into their given problem area.
. . . appreciate the factors that can effect team performance.	Approximately 50% of the project deliverables were the result of team work.

* Students used the project to build skills developed in other modules in the following software packages: Adobe Photoshop, Adobe Illustrator and Ideas (further information available from www.adobe.com/products/photoshop/main.html, www.adobe.com/products/illustrator/main.html and www.ugs.com/products/nx/docs/br_ideas.pdf respectively).

Table 3. Relationship between the project and other modules.

Integration with other modules	How addressed by the sustainable design project
Psychology	Not explicitly—however the need for individuals to take responsibility for the future touches upon aspects of human behaviour that student learn in their psychology modules.
Marketing	Market research and positioning was a key aspect of the many students' research work.
Contextual studies/architectural history	By researching the current situation, students were able to carry out a design project in the context of both the future situation that they had envisioned and the products that are currently available.
Mechanics	Students were able to make qualitative assessments but the project did not result in a sufficiently detailed design to enable detailed quantitative analyses.
Electronics	A number of students defined briefs that used renewable energy sources to power their products. Students needed an awareness of the power requirements to assess the feasibility of using such energy sources.
Materials	Material selection was a key part of the project—see earlier.
Design Technology Management	Product and supply chain structures impact recycling feasibility

Table 4. Relationship between the project and design communication skills.

Skills development	How addressed by the sustainable design project
Sketching	In individual folio pages and posters.
Requirements definition & design evaluation	Requirements were defined and designs evaluated with respect to them.
Computer Aided Illustration software use	Used in the production of posters and portfolio pages.
Computer Aided Design software use	Used in the production of CAD models for posters and portfolio pages.
Personal skills: literacy, team-working, presentation & time management	The completion of individual and collection of projects required these skills.

Table 5. Summary of the assessment of work submitted.

Item	Mean mark	Tutors' comments
Week 4 team posters	70%	The performance in this phase of the project was excellent. It was clear that each team had engaged with the project and the volume of work completed, and the sustainable development information gained was impressive.
Week 6 team visions	66%	The team visions were, on the whole, good. They demonstrated that the students had built upon their design research and thought about how the situation might change in the future.
Week 6 individual briefs	57%	Over 80% of the original individual briefs that were submitted did not answer the two questions that were used to assess the feasibility of each student's Phase III project: (a) what is the product that you are going to design? (for example, a mobile phone) and (b) what is your sustainable design goal? (for example, to reduce the frequency at which people replace their mobile phones.)
Week 11 progress	49%	The majority of students had not made significant progress at this stage of the project. Two factors contributed to this. Firstly, it is difficult to carry out a design project when the brief that has to be delivered is unclear and/or infeasible. Secondly, the workload from other modules in the course was high by this stage in the term.
Week 18 final portfolio pages	56%	The final portfolio pages were strong in their use of the team design research. Approximately half of the students submitted designs that needed more detailed definition to remove ambiguities. Despite the fact that the material selection workshops were a part of the project, a significant number of students did not provide evidence in their portfolio pages of having used this software as a part of their design process.
Week 18 CAD models (digital prototypes)	50%	The quality of the Ideas models that were submitted spanned a wide spectrum. In part this was due to the variable CAD skills of the students concerned. In addition, students with incomplete product definitions in their portfolio pages had additional difficulties since CAD packages such as Ideas do require the user to be specific in the detailing of their geometric definitions.
Week 20 team posters	59%	All but one team submitted a complete poster that included their design research, team vision, and individual briefs and designs.

The project was originally scheduled to run for 18 weeks but this time had to be extended to 20 weeks. Delays arose in Phase II of the project when it was found that students needed more guidance and support than anticipated in defining their individual briefs. The results of this phase had to be carefully monitored to ensure that each student had an individual design project (in Phase III) which was feasible given the time available and the experience and knowledge of the student concerned. In some cases, additional time was needed to negotiate individual briefs. On reflection, it was too early in the development of the students and their time on the course to ask them to set their own brief, but it showed where facilitation is needed, which is part of the whole process of project learning—the role of the tutors changes and they also have to react to situations as management would in real life [11]. In future years it is anticipated that the two key questions that the brief needs to answer will be included in the Phase II project brief so that students can assess the risk of their own project before submission of the brief. In addition, studio session will be added to provide background on the purpose of a design brief and how one is set up (for example, what is fixed, what is not; what is achievable, what is likely to pose difficulties). Care will be taken to ensure that each student defines a brief that is open and emotionally driven rather than a detailed technical specification.

Students will be briefed on issues surrounding the changing of the rules (to give a vision of a possible future) via, for example, a thought-provoking exercise.

What are the things that you like about the module?

- Sustainable design – It was well planned, well put across, enjoyable and is very easy to be motivated for.
- Sustainable design project was well planned and well thought out. Involving the use of relevant information previously learnt. Enjoyable but also challenging.
- The sustainability part of the module. The task we were given was very relevant, interesting and something we can produce a good standard of work for. Like the influence of David Raffo who has knowledge of the design industry. The project was challenging and allowed us freedom to think and go into some depth on the subject.
- Assessing the importance of sustainability

How do you think the module could be improved?

- Put far more work into sustainability project.
- LESS GROUP WORK! Why are most things done in a group? How can you effectively assess individuals' work?
- Assessed design, more time, more designing.
- More sketching and Design based work
- More design help, showing us the best way to illustrate design.
- Individual work.

Fig. 5. Student feedback

FUTURE DEVELOPMENTS

The project was well received by students and the students produced some excellent work. Improvements are planned in three broad areas for the next delivery of the project which will be to approximately 50 students: project delivery, assessment and organization.

Project delivery

The content of the project in terms of the new knowledge gained by the students was appropriate and the use of the project to enable students to gain detailed knowledge through focused research in teams was found to be effective. However, an analysis of the students' performance indicates that more support is needed in the development of design and personal management skills. In particular, it is anticipated that a workshop session on the definition of a design brief will be added to support students better in this aspect of the project. This session will be supplemented by clearer guidance on what is expected in a brief and more focused assessment criteria for the brief. The brief itself will still be open, focused on future solutions rather than current technical issues, and students will be encouraged to create innovative designs for the future rather than detailed technical solutions for today.

With respect to personal management skills, the lack of progress in week 11 of the project (which was reflected in the low average mark for the assessment of progress to that point) will be addressed by the addition of a progress report which students will submit in week 11. In this report, it is anticipated that students will list work done since the submission of the Week 4 poster. As such it will include the team vision, the individual brief and, in some cases, revised drafts of the brief and communications with design supervisors to negotiate the brief.

Assessment

The frequency of assessed deliverables in the project was too high at some stages. For example, the submission of the Week 6 poster was so close to that of the Week 4 poster that students had insufficient time to create their team vision and tackle the most challenging task—the definition of their individual briefs. For the next delivery of the project, the requirement for the Week 6 poster will be removed and the final poster will be defined to include 2 $\times$ A3 sheets: a revised version of the Week 4 poster (to include the team vision) plus the individual briefs and design solutions.

At the end of the project, there was some time pressure caused by the need to create a CAD model of the finished design. In addition, some of the designs were not well suited to being modelled in a CAD package because, for example, they were made from flexible (non-rigid) materials and so violated the rigidity assumption that underpins solid model-based CAD systems. Finally, the completed CAD models did not add significant value to the design portfolio pages or posters; it was felt that student time devoted to the creation of the CAD model would have been better spent detailing their final designs and the portfolio pages through which the designs were communicated. For these reasons, the computer aided illustration element of the project will be kept for the next delivery but not the use of the CAD system.

It can be seen that the assessment of the project included both process and product focused elements [9]. From an analysis of the portfolio pages that were submitted, the assessment schedule

Table 6. Revised portfolio page assessment schedule

	Outcome of the design process		Execution of the design process	
Mark	Final design definition	Concepts considered	The extent to which the design satisfies the brief and the way in which design decisions are justified	Use of personal research and information from other modules
over 80%	An original design with sufficient detail to show clearly how the design functions and how it might fit in the environment for which it is intended.	An extensive range of original concepts that apply a wide range of solution principles.	Decisions clearly justified through systematic evaluation with respect to clear design objectives with a clear link to the brief. Thorough evaluation using both quantitative and qualitative data, and weighting of evaluation criteria.	Learning from both a wide range of modules and results of personal research drawn from a number of sources used to address a number of design issues.
70–80%	An original design with sufficient detail to show how the design functions and how it might fit in the environment for which it is intended.	A good range of original concepts that apply a range of solution principles.	As above but with minor weaknesses, for example, some design objectives not considered or criteria not weighted.	Learning from a range of modules and results of personal research drawn from a number of sources used to address a number of design issues.
60–70%	An original design with sufficient detail to show how the design might function and/or how it might fit in the environment for which it is intended.	A reasonable number of original concepts that apply a range of solution principles.	Decisions clearly justified through a systematic evaluation with respect to clear design objectives with a clear link to the brief. Evaluation using both quantitative and qualitative data, and, for higher end of range, weighting of evaluation criteria.	Material from some modules and/or results of personal research used to address a number of design issues.
50–60%	An original or (for lower marks) a derivative design with insufficient detail to show clearly how the design might function and/or how it might fit in the environment for which it is intended.	Several original concepts that apply more than one solution principle or a wide range of derivative concepts that use similar solution principles.	Outcomes of decisions stated but not clearly justified through a systematic evaluation with respect to clear design objectives with a clear link to the brief. Evaluation using largely qualitative data.	Material from a small number of modules and/or results of personal research used to address a small number of design issues.
40–50%	A derivative design or an incomplete design solution. Insufficient detail to show how the design might function or how it might fit in the environment for which it is intended.	A small number concepts with insufficient detail to enable the application of solution principle to be seen.	Unsubstantiated assertions made and clear to see as being correct but not supported with evidence.	Material from modules and/or results of personal research included but not used in the design work.
Fail (pass mark is 40%)	Very little detail; not possible to identify what the product might be.	Very few concepts with very little detail in the definitions.	Not addressed or unsubstantiated assertions made that do not appear to be correct.	No material from other modules or results of personal research included.

given in Table 6 has been created and will be used as a guide in the marking of the students' portfolio pages in future deliveries of the project described in this paper. This schedule will be made available to students during the project in order that they might review their work before it has been submitted.

Project organization

The final area for improvement lies in the organization of the project. As stated earlier, Hansen *et al*. reported [12] increased demand on teaching resources as being an issue in the introduction of project-based learning.

As a result of previous experience of student design projects, a decision was made to use electronic submission of all assessed materials apart from the individual portfolio pages*. This meant, for example, that students would not experience delays in trying to print large (both in memory and physical area) poster files, staff would not need to manage large quantities of paper and the problems of secure submission and return of coursework would be avoided. The necessary computing infrastructure was established and the majority of

* Electronic submission of portfolio pages was not required because students were expected to work on them when they were away from the university and without access to the mecessary computer facilities.

students used this as intended. The management of the work that was submitted correctly was significantly easier than with paper submissions and a significant amount of staff time was saved because all submitted materials were available electronically when needed. However, in the first delivery of the project reported in this paper, a significant additional workload on staff resulted from undisciplined use of the computer infrastructure by a minority of students. For example, students were asked to submit their posters as .pdf files and these plus team meeting documents (for use as evidence in peer assessment) were to be stored in a predefined shared computer area. CAD models were to be submitted using the system libraries. In practice, some of the .pdf files had not been checked and did not contain the correct information, posters were submitted in non-pdf formats and could not be read at all, some students emailed large files to staff which created email system problems for both themselves and the recipients of their messages and CAD models were submitted in non-standard ways which meant that the models could not be viewed. As a result, a significant amount of staff time was consumed in attempting to read poor quality electronic submissions. In the next delivery of the project, clearer instructions regarding the submission of computer files will be made explicit and the consequences for students of failing to follow these instructions will be defined.

DISCUSSION

What should students learn in sustainable design projects?

Most sustainability problems are system problems (for example, transport or food consumption) and almost insoluble. To address sustainability issues, designers need to be able to understand design problems in context, envisage and describe better future systems, and then design products that could be part of a new improved system. This aligns with one of the specialist skills for designers identified through the United Kingdom Design Council's Design Skills Campaign†, namely, envisaging future needs. The design project described in this paper, by starting with an investigation of a current situation and leading to a future vision, allowed students to gain experience of envisaging a future. A key challenge for students was how to articulate both their current situation and their vision of the future. One of the limiting factors for students in the implementation of the project described in this paper was the lack of any systematic means of describing their present and future situations. In the third year of their programme they will learn how use soft modelling techniques to build models of envisaged scenarios [13]. It is anticipated that, through this learning, students will both build skills in systems thinking and be able to use these approaches to consider, in a more systematic fashion, the systems within which the products they design will sit. Most problems in the future will be sustainability driven, in the widest sense, or contain a high element of sustainability and so sustainable design skills are likely to become increasingly important in students' futures.

Referring back to the framework presented in Fig. 4, in defining their new situation, students needed to analyse the existing situation they had defined. This analysis should encompass as wide a range of aspects of sustainable development as possible. For example, the five capitals approach highlights social, economic and environmental factors as well as interplays between them [2]. Ideally the analysis will include both quantitative and qualitative results so that objective design evaluations can be carried out later in the design process, when design alternatives are being evaluated. In addition, students need to recognize the limitations of what they are likely to be able to achieve as lone practitioners, though in the student situation they can and should be more experimental than they may be allowed in professional practice. In part this leads to a need for the development of attitudes and working practices that are compatible with effective team working. Through consideration of ethical dimensions of sustainable development, for example, professional responsibility, students can gain an appreciation of how practising designers might fit within the wider community and the potential social impact of their work.

Having identified the new situation, and with an awareness of the analysis results, students can look for design opportunities for new products that would enable the delivery of the new situation. Having identified an opportunity, a key skill that needs to be developed is in the creation of a design brief that is both technically feasible and deliverable using the resources that are available. In the project described in this paper the two critical resources were the students who were going to carry out the design project and the time that was available. The time available was considered in two ways: as the elapsed time (defined by the project schedule) and the person hours available. The available person hours for this project were nominally defined as 100 hours less the time used for research; however, in practice, the available person hours are a balance based on the commitments that the students have both within their course and outside university.

A key element of any product design process lies in the selection of materials. For sustainable design projects, students need to learn about the characteristics of materials as they influence sustainable development and how to use material selection techniques in their design processes. Within the project, the necessary knowledge was delivered

† For details of the United Kingdom Design Council's Design Skills Campaign, go to www.designcouncil.org.uk and search for *Design Campaign Skill.*

through a materials science module and the use of state-of-the-art materials selection software (CES4—see earlier) was taught through workshops that were a part of this project.

Datschefski [14] gives five factors that he uses to identify sustainable products.

- Cyclic considers whether a product is a part of a natural closed loop (or complete recycling) or not;
- Solar considers whether the energy used to make and run a product is from renewable sources;
- Efficient refers to the efficiency of materials and energy use;
- Safe considers whether or not products, and their by-products, contain hazardous materials;
- Social relates to whether the manufacturer of the product exploits workers.

These can be used to influence the evaluation of design alternatives but, in many circumstances, opportunities for objective evaluations of design alternatives are limited. For example, given Datschefski's definition, the social impact of a product may be more closely related to decisions made in the light of a manufacturing strategy rather than during a design process. Thus, in considering design alternatives, students need to recognize the limitations if they are not involved in downstream decisions such as production.

Of the five capitals identified by Strong and Hemphill[2], environment is the one which has received the most popular attention. There is a wide-ranging literature on eco-design which can be used to inform the evaluation of the potential environmental impact of design alternatives. Life-cycle analysis, in one form or another, lies at the heart of the majority of eco-design approaches. Such analyses require knowledge of both the relevant downstream processes and detailed product definition data. Feldman *et al.* propose a product structure-based approach at the end of life analysis [15]; again, this requires detailed product and process knowledge and an awareness of the notion of a product structure. For the project described in this paper, the idea of a product structure was identified in the design technology management strand of the programme.

As with many process analyses, there is also a need for information relating to the network of organizations that will execute the end of life processes. The structure of a supply chain frequently mirrors the structure of the product being manufactured (McKay & de Pennington, 2001). Some of the student teams in the project included return chains that mirrored their product structure. Thus, sustainable design learning should ideally include the mapping of a product, end of life process and resulting enterprise network structures so that the full impact of the design might be considered. Given that it is unlikely for one person to have all of the necessary knowledge, the importance of being able to work in teams is obvious.

CONCLUDING REMARKS

The design and delivery of our project has demonstrated that project-based learning is an effective way of delivering student learning in the subject area of sustainable design. In addition to detailed technical knowledge and design skills, successful sustainable design requires context and understanding. As such, the purpose of this project was not only to allow students to acquire new technical knowledge but also to open the students' minds to what the design world is really about. The project allowed students to gain insights that are the keys to the future of innovative design and the managed process of the project. The inevitable complexity of the whole project was managed through phasing. In this way, in the later phases of the project, students were able apply their design skills and technical knowledge to a relevant design problem. The relevance was created through the students defining their own briefs, linked to their own design research. This allowed them to put themselves into their own future and so, to some extent, humanize it. The project itself was mentored and supported, guided and encouraged rather than being taught in the traditional sense in order to get the best out of the students and allow them to become the innovators that industry needs. In addition to developing design skills and knowledge, the project allowed students to gain first-hand experience of challenges to be addressed in the realization of sustainable products. More broadly, it demonstrated that the framework for the definition of sustainable design projects could be used to compare and contrast different projects that students are presented with during their studies. Learning gained through the project has informed the identification of key elements needed in a sustainable development curriculum for product designers.

The project could be adapted to suit other courses by changing the project areas (Phase I) to ones that align with the subject of the course concerned. In selecting the project areas it is important to relate them to systems level problems rather than specific design problems or solutions (see Fig. 4). The scale and extent of the project depends upon what the final deliverables of Phase III are defined as being.

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Prof. David Raffo is a Royal Academy of Engineering Visiting Professor in Engineering Design for Sustainable Development in the School of Mechanical Engineering at the University of Leeds. He is a founding partner of Raffo Design and also a director of several companies involved with innovative product development. As a director he has guided Raffo Pape and Woodward to being the leading European pre-school toy innovation group with major product ranges for Fisher Price, Tomy and Hasbro. As founder and now Chairman of Raffo Design he has led the development of Raffo's award winning consultancy as a research and customer focused product development business with clients worldwide. David is an experienced teacher and hands-on skill developer, having lectured widely at colleges and universities, presented the 'Business of Design' lectures at Manchester Business School and at seminars across the UK for the Design Council on all aspects of New Product Development.

APPENDIX

Project definition

INTRODUCTION / PURPOSE

Sustainable development is becoming an increasingly important issue for designers to consider. Sustainability embraces a very complex blend of issues that includes social, economic and environmental issues. Most of our current world is unsustainable from the growth in use of motor vehicles, through the 'disposable' culture to unfair distribution of wealth from labour but we struggle to find 'complete' solutions ourselves so we cannot ask students to.

The aim of the whole project is for students to build up a clear view of the 'context' of a given problem and a potential 'answer' to that situation which had merit and gave 'direction' to a more sustainable future in a 'step' that could be applicable today even if it is not actually achievable in the short-term. Most sustainability problems are system problems [transport/cars/out of town shopping] and almost unanswerable. Designers need to understand the problem in context and 'vision' a better system that they could describe, then design a 'product' that could be part of the system of the future.

BRIEF

The project is broken into the following three phases. Briefs for each phase can be found through the following links.

– Phase I: Research / Context setting
– Phase II: Scenarios / Product visioning
– Phase III: Concept design

PROJECT SCHEDULE AND ASSESSMENT

PDES2140 is a Level 2 module whose mark can influence degree classification. For this reason, students' individual contributions to the Sustainable Design (SD) project teams will be assessed. This assessment will be made using information from two sources: peer assessment from students and judgements made by staff. To support these judgements, each student team is required to provide documented evidence (in the form of meeting agendas and minutes) in addition to personal impressions of the contribution each student made. It is anticipated that each team will meet at least once a week.

PROJECT ASSESSMENT

The project mark will be compiled in the following way.

	Weighting	Individual / Team
Phase I	10%	Team
Phase II	5%	Team poster
	10%	Individual briefs
Phase III: Progress reviews in Week 11	10%	Individual
Phase III: Interviews in week 20	40%	Individual
Completed poster (Note: the majority of the work on this poster will have been completed before week 6.)	25%	Team

TEAM ASSESSMENTS

The team assessments will include an element of peer assessment. Two sources of information (team meeting documents stored in each team's P drive area and individual comments from each student) will be used to inform the peer assessment and, therefore, the individual marks for each member of the team.

POSTER COMPETITION

The best poster will be submitted to RAEng national competition and will be entered into a faculty wide SD competition. The RAEng VP scheme has £500 prize money for SD related project work - this will be divided between the two individual students with the top marks for this project and the two project teams with the best posters .

RESOURCES

– Edwin Datschefski, "The Total Beauty of Sustainable Products", RotoVision SA 2001, ISBN-2-88046-545-1
– RAEng Principles of Sustainable Design booklet

ACKNOWLEDGEMENTS

The development and delivery of this project has been supported by the RAEng (Royal Academy of Engineering) through its Engineering Design for Sustainable Development Visiting Professors Scheme. As a part of this scheme, prize money of £500 is available for the best projects. The winning poster will be entered into a national poster competition that is run within the RAEng scheme.

Fig. 6. Phase I project definition and brief.

Area 1: Small domestic products

Productivity and efficency has made small domestic products very cheap [for example, personal CD player less than £10, hairdryer less than £15]. This frames our attitudes to buying them, using them and changing them.
At such low cost too many are disposed of, is this sustainable?
What are the issues?
What alternative industrial ways may there be?
Would social or tax changes alter the picture?
What may products be like then?

Area 2: Mobile phones

Mobile phones are a specific case of the above. They are not cheap but pricing structure gives the impression that they are. Four million are disposed of each year in UK alone. We are addicted to communication but is price acceptable?
What alternatives are there?
How much fashion do we need?
What parts of a phone are expensive/dangerous/reuseable?
Tariff change?

Area 3: Mobile food

For example, look at the issue of disposables on a train journey or medium haul flight. New trains provide the lifestyle food and beverages we would like but all the packaging is thrown away, and it's a lot. For one hot drink you get cup, lid, stirrer, napkin and printed both sides carrier bag. If we imagine in the future there was a huge tax increase in the charge for generating this sort of waste what would be good system solutions and what would be neat, cool products that would fit with this system ?
What could change this?
Could train layout help? Different staffing?
What would people be prepared to do themselves?
Could we add a social dimension?

Area 4: Supermarket Shopping/Out of Town Shopping

It is almost impossible to go shopping without a car raising environmental and socal issues.
Internet shopping raises other issues, would we need less packaging because you never see product until it arrives at your door but does it create more traffic?
How could basics be delivered more effectively ?
What will happen as the population all get older ?

Fig. 7. Phase II project definition and brief

PHASE I: RESEARCH / CONTEXT SETTING

Phase I is the 'contextual' part of the project. It is to get students to see that there are some real problems out there, to consider the issues briefly from environmental, economic and social viewpoints and to do some basic research to find the scale of the problem and what may or may not be happening to find better ways in the future.

In week 4, once you have completed this initial research, the whole project will be introduced.

Brief

You have been assigned to a team and, in that team, one of four project areas.

Click here to see the team details.

Consider the project area, and products within it, under the following headings.

Environment
What are the products made of? Why?
Can they be recycled? How?
How big is problem?
What laws might change this?

Ecomomic
How do we pay for these products?
What would happen to workers/industry if we change?
Can this be a positive change?
Would business be a better business?

Social
Is it fair?
Does it affect different age groups in different ways?
Different social groups? Is it only for the rich?
Can the elderly use this?

Produce a poster using the Adobe software (Illustrator and/or Photoshop) and present it using the projection system at the studio session in week 4.
The poster should characterise the current situation (for example, by giving key statistics) and highlight sustainability issues.
The presentation should last no more than 10 minutes. You may choose whether one, some or all of the team deliver the presentation.

Assessment

This project as a whole will have two key deliverables: a team poster and individual concept designs.The final poster will cover all phases of the project. The content of the poster created in this phase of the project will form a part of the final team poster.

The Phase I poster is worth 10% of the project mark.

It will be assessed equally against the following criteria:

- clarity of message
- visual impact
- approapriate graphics
- not too much text & text linked to graphics
- demonstration of an understanding of the issues

Submit the poster electronically on Friday 15th October.
Follow this link for details of how to submit the poster electronically.
Staff will ensure that the posters are available for presentation in the week 4 studio session.

Resources

- Edwin Datschefski, "The Total Beauty of Sustainable Products", RotoVision SA 2001, ISBN-2-88046-545-1
  (copies of this book should be available through the University Library)
- RAEng Principles of Sustainable Design document
  (copies will be available in the Design Studio from week 1 or Click here for an electronic version)
- David Raffo's lecture notes from PDES1180.
  (copy available in Design Studio or Click here for an electronic version)

Fig. 8. Student feedback.

PHASE II: SCENARIOS / PRODUCT VISIONING

Introduction / Purpose

Phase I was the 'contextual' part of the project. It was intended to get students to see that there are some real problems out there, to consider the issues briefly from environmental, economic and social viewpoints and to do some basic research to find the scale of the problem and what may or may not be happening to find better ways in the future. In week 4, once you have completed this initial research, the whole project will be introduced.

Most sustainability problems are system problems [transport/cars/out of town shopping] and almost unanswerable. Designers need to understand the problem in context and 'vision' a better system that they could describe, then design a 'product' that could be part of the system of the future. In Phase II of the project you will use the results of your research, and what you have learnt from seeing the presentations of other SD teams in the week 4 studio session, to build up a clear view of the current situation in your chosen area and, from that, produce a vision of a better system. The third phase of the project will involve the design of a product that could be a part of this vision.

Phase II Brief

Create a definition of the current situation of your problem area and use it as a basis for identifying how the situation might be different in 10-15 years time. Think about, for example, what drivers will have changed - legislation, demographics, lifestyles, etc. This is your vision of the future.
From this vision identify needs for new products and, from these needs, develop a series of design briefs, one per student.

This phase of the project has two deliverables: a team poster and a set of individual design briefs.

Individual design brief

The web pages containing each brief will be asssessed individually and will be worth 10% of the project mark. In assessing the briefs we will be looking for the following:

- evidence of links between your brief and the research that your team carried out;
- an aspirational and futuristic technical specification that fits with your team's vision and includes clear goals;
- where possible these goals should be quantifiable;
- at least some of these goals should be quantifiable.

NOTE: The designs that you create in Phase III of this project will be evaluated in terms of how well they satisfy the brief. At this stage it is important to be thinking about how you might demonstrate that your final design satisfies the brief. In particular, the objectives defined in your brief need to be measurable, achievable (given the time and other resources that are available to you) and realistic.

Fig. 9. Briefing materials for tutors leading the Week 2 tutorial.

PHASE III: CONCEPT DESIGN

NOTE: You are advised not to start this phase of the project until after the interactive sessions in week 6 because individual briefs may be modified at this stage.

Assignment

This is an individual project.

Design a product that satisfies the brief that was agreed in week 6 of this project.

Submit 8 x A3 design portfolio pages that shows the following:

– how you translated the design brief into a collection of design objectives;
– how your ideas developed through the project;
– how you applied what you learnt in this and other modules to this design task;
– how you evaluated alternative concepts through the design process;
– how you decided which design concept to take forward to your final design;
– how you developed the final concept into a form that could be used to create the digital product definition (Ideas model).

Submit your design portfolio pages by 5pm, Friday 4th February 2005 to Mr Bob Bows in the Design Studio.

Submit electronically your digital product definition, in the form of a CAD (Ideas) model of your design, by 5pm, Friday 4th February 2005.

Assessment

This assignment is worth 50% of the total project mark. The marks will be distributed in the following way:

– 10% progress reviews in Week 11 (failure to attend at the specified time will result in a mark of zero being assigned for this part of the project). Follow this link to see the marking scheme and schedule for the Week 11 progress reviews.
– 80% design portfolio pages
– 10% digital product definition - CAD (Ideas) model

The following assessment criteria will be used to assess the design portfolio pages.

	Criterion	**Weighting**
Design process	interpretation of the brief	8%
	use of design skills and learning from other modules	8%
	extent to which the development of your ideas is recorded	8%
	extent to which the decisions you made are recorded and justified	10%
	presentation	12%
Project results	quality and extent of the design objectives that you used and their relationship to your brief	8%
	quality and extent of the design concepts that you developed	12%
	quality and extent of the final design	12%
	rationale behind design decisions that were made	12%
	extent to which the design objectives are met by your design	10%

The most important thing in the CAD presentation is that it is a visually exciting response to the brief and that will be a key judgement. The technical CAD appraisal will be reviewed but play a lesser role than in the past.

The following assessment criteria will be used for the CAD model.

	Criterion	**Weighting**
Visually exciting response to the brief	visual impact	20%
	relevance (with respect to the brief and the final design)	20%
	the quality, extent and coverage of the model	20%
Technical construction of the model NOTE: The model will be viewed as a shaded image and from which an exploded assembly will be generated	parts appropriately placed in the assembly hierarchy	8%
	appropriate mating conditions specified	8%
	absence of spurious parts and other elements	8%
	appropriately named assembly and parts	8%
	reasonable assembly structure	8%

Fig. 10. Phase III project definition and brief.

Individual interviews to review progress will be held during the timetabled studio session in week 11. Click here for the week 11 schedule.

Attendance at these interviews is compulsory.

Performance at the progress review will contribute 10% of the individual mark for this assignment and will be assessed against the following criteria.

Criterion	**Weighting**
Attendance at scheduled time	20%
Well prepared with a small number of substantive questions and/or subjects for discussion	20%
Plan for how project will be completed	20%
Draft concept designs and presentation materials available for review	40%

Fig. 11. Assessment for Week 11 progress review.

PDES2140: Design Studio 2 tutorial – week 2

Introduction

A number of students have raised concerns regarding the different individual contributions that students make in team projects. Given that PDES2140 is a Level 2 module, whose mark can influence degree classification, we are going to assess individual contributions to the Sustainable Design (SD) project teams.

This assessment will be made using information from two sources: peer assessment from students and judgements made by staff. The process of judging individual contributions will need facilitation and I'll do that facilitation, at least for the SD project. To support this facilitation, I would like each of the student teams to provide documented evidence in addition to personal impressions of the contribution each student made.

The documented evidence should be in the form of meeting agendas and minutes; the delivery of the the meeting documentation will form a part of the project. All students have been put into teams that address their preferred problem area. Each tutor group will include students from a number of different project teams. The teams were published at the end of Intro week and the students have been told to start meeting before the end of week 1. A team list and the instructions they have already been given are attached to this note.

Purpose

In this tutorial the students will reflect upon past experience of team working and learn how to make agendas for and minute team meetings.

Tutorial agenda

The tutorial will follow on from PDP, and the need to reflect on one's own performance and achievement and create portfolio of evidence for work/interview/career situations.

- Please spend 10/15 minutes on the following questions:
  - What makes teams work effectively?
  - Does everyone agree on what an "effective" team is?
  - What makes teams ineffective?
  - What ideas do students have about identifying individual contributions to team projects?
  - For each student,
    - write down how you did and did not contribute to effective teams last year,
    - what do you need to do to be a better team member? (for yourself and the team)
  - How could a team create documentation to demonstrate it is working and gain credit for it?
- Then spend 10/15 minutes on the following
  - When the SD teams met last week,
    – what was the purpose of the meeting?
    – what did they achieve?
    – what are they all going to do next?
    – what is the purpose of the next meeting you're going to have?
    – Did they have an agenda and did anyone take minutes?

Suggested items to include in each meeting Agenda

Each project meeting agenda should include the following items. More items can be added if necessary but it is important, to maintain continuity, to always review actions from the previous meeting, review progress against a plan and confirm the actions from the current meeting so that everyone knows what's happening.

NOTE: Please remind students that if actions are identified for a student who is not present then it's a good idea to add an action for someone at the meeting to specifically inform the absentee that they have some actions.

– Confirm minutes of previous meeting
– Review outstanding actions listed in the minutes
– Review progress (ideally against a project plan that was agreed in first meeting)
– Confirm actions from this meeting
– Confirm Date of Next Meeting (DONM)
– Any Other Business (AOB)

Fig. 12. Briefing materials for tutors leading the Week 2 tutorial.