# AN ENGINEERING DESIGN COURSE: DEVELOPMENTS OVER FIVE YEARS EMPHASISING TOPICS OF SUSTAINABILITY

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**Abstract:** Engineering design is a core subject in many Engineering departments and is greatly valued by future employers. Over five years a second-year engineering design course has been nurtured to focus on developmental projects associated with sustainability which emphasise hands-on learning. Students work in groups, with recent projects focusing on the design of domestic scale wind turbines. The design is taken from concept through manufacture to final testing using a wind tunnel. The commercial and societal relevance of the project is emphasised, as is the need for team working. Each team is given a budget of £100 (€110). The majority of the timetable is devoted to laboratory sessions where hand and power tools are available. Assessment methods include presentations, formal reports, 'weekly updates' and individual logbooks. Learning outcomes are based on UK-SPEC. Creativity and innovation are encouraged during the design process. Regular assessment occurs throughout with an emphasis on rapid, formal feedback. Student feedback improves year on year with typical student attendance above 90%. The number of students taking the Design degree stream doubled last year. The key features which have led to success are allowing students to take a paper design through to manufacture (encompassing the hands-on and 'realistic' aspects of engineering) and trusting in students' creativity. Both areas led to students having a sense of ownership of their learning and developing into professional engineers. Assessment workload for staff is high but is seen by students as evidence of staff commitment to their learning.

*Keywords;* sustainability, project-based learning, hands-on learning, problem-based learning, andragogy.

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## 1. INTRODUCTION

The School of Mechanical and Systems Engineering School at Newcastle University in the UK currently offers a three-year BEng degree in Mechanical Engineering together with a suite of four-year MEng degrees in Mechanical Engineering based disciplines. All degrees are accredited by the Institution of Mechanical Engineers or the Institution of Engineering and Technology. As with many such degrees in the UK, engineering design is seen as a core subject. At the School of Mechanical and Systems Engineering, engineering design is taught at first and

second year. First year Design is a 20 credit module which includes: the study of structures; an introduction to AutoDesk® Inventor® solid modelling software, the production of engineering drawings; an introduction to BS8888 (the British Standard on Technical Product Documentation, specifically the Specification for defining, specifying and graphically representing products); a bridge design, build and test exercise; and an introduction to machine shop equipment and processes.

In the School of Mechanical and Systems Engineering, a second year cohort typically consists of 70 students, though this number increased markedly to 94 in the 2009-10 academic year. The second year Design module was worth 15 credits (out of a total of 120 credits for the year) and teaching took place over two terms. Four hours per week of contact time were allocated, broken down into a one-hour lecture and a three-hour slot where the students worked in their groups. Beginning in the 2005/06 academic year, students worked in pre-assigned groups of 5. Through an ongoing Knowledge Transfer Partnership (KTP) [a UK government sponsored scheme to encourage interaction between universities and industry] that one of the authors had established, a design project was set up with a local company which manufactured Caravans (Explorer Group, Consett, UK). Projects in academic years 2005-06 and 2006-07 concerned the design of folding bed mechanisms. Each were 'paper' exercises in that the final output included a full set of engineering drawings and a written group report, although one student won a summer placement with the company and his design went into production the following year.

Assessment was by a group presentation and a group report at the end of each term. Groups were told to decide on the allocation of marks for group members. In addition, in part as a method of assessing and rewarding individual contributions, each student had to keep a 'logbook' which served as a contemporaneous record of their contribution to the design project. Logbooks were assessed at three points: early in term 1 to check that fundamentals were being adhered to; at the end of term 1 alongside the group 'interim' reports; and at the end of term 2 again alongside the group 'final' reports. In summary, assessment was completely through course work and consisted of the following components: logbook; interim group report; final group report; interim presentation and final presentation.

*1.1 Module developments since 2007*

In 2007, following the departure of the previous module leader, the lead author of this paper was appointed module leader. This also meant that the second year Design module was reduced to three members of teaching staff (the authors of this paper). Based on previous experience of teaching the module, discussions with colleagues, feedback from students and various pedagogical ideas, specific changes were made to the module which were intended to improve the student learning experience. Some aspects of the Design course were maintained. Group projects based on open-ended learning were continued to ensure that creativity was prioritised and that students had a sense of ownership of their project and thus of their learning. In addition, those aspects of the marking methodology based on peer-informed assessment were maintained. Assessment continued to include individual logbooks, and interim and final group reports. However it was felt that improvements could be made. Firstly, student feedback supported comments by staff that a caravan based project was somewhat lacking in inspiration. In addition the authors felt that a more socially relevant and topical engineering project would enthuse the students more. The academic year 2007-08 project was entitled 'greening our homes'. The

design project initially required students to come up with three conceptual designs of domestic scale energy saving devices or energy generation devices. These three concepts were described in a 3,000 word interim report after which one concept was taken forward and designed in full during the second term. This description formed the basis of the 3,000 word final report.

One key aim was to introduce concepts related to sustainability. As will be appreciated these concepts can apply to many areas of engineering. In the earlier projects they could have been applied to caravans. However concepts of sustainability were explicitly stressed when the new module leader took over. Therefore issues such as choice of materials, considerations related to recycling etc were emphasized to students and sustainability was made one of the marking criteria which were shared with the students. In addition, issues related to global warming and fossil fuel usage were covered in an early lecture so that the context of the need for sustainable power generation was set at the beginning of the module.

In the academic year 2008-09 access to student workshop space was obtained as well as a wind tunnel. The 2008-09 design topic had a title of 'from kilobytes to kilowatts'. Here, ten groups of students, of no less than seven per group, were initially given a redundant computer and printer. From these they had to design and manufacture a wind turbine, which was tested in a wind tunnel at the end of the first term. No additional material or components were permitted. In the second term, having learnt from this experience, each group was given a budget of £100 and allowed to take their original design of wind turbine forward, or re-design, as they saw fit. In both terms, laboratory space was set aside for manufacture and assembly of the wind turbines using basic hand tools.

There were concerns over the assessment methodology and burden from previous years, especially when staff numbers had been reduced from four to three in 2007. Having two 'peaks' of assessment at the end of each term was felt to reduce student effort at the early and mid-term points. Therefore the final presentation was removed, while the interim presentation was reduced in duration, as these were felt to take up a significant amount of student and staff time when the bulk of the assessment marks was obtained from the project reports. Marks which had been allocated to the presentations were passed to a new form of assessment, named the 'Weekly Update'.

Over the course of the two terms each group had to submit seven Weekly Updates. Each Weekly Update consisted of two sides of A4. The first side aimed to summarise the previous week's project work by asking open-ended questions such as: what information sources had been investigated and what data had been gained from them; how had the design progressed that week; what challenges had been overcome; and what were the aims for next week. The intention of these questions was to allow students to see the progress they had made and appreciate their successes in the design process. It also mimics the sort of progress report required in industrial design and production projects.

The second side of the Weekly Update listed the parts of UK-SPEC which it was felt the Design module covered. UK-SPEC are the components by which degree courses offered by UK higher education institutions are assessed for accreditation by the engineering institutions. It is also the standard by which Chartered status (similar to PE in the USA) is obtained in UK and many

international Institutions. Components of UK-SPEC are grouped into areas including: E - Engineering Analysis; D - Design; S - Economic, Social & Environmental Context; and P - Engineering Practice. As just a few examples of the 18 that were felt to be covered by the Design module, these included: D4 – use creativity to establish innovative solutions; P8 – ability to work with technical uncertainty; and S3 – understanding of the requirement for engineering activities to promote sustainable development. These UK-SPEC components were shared with the students so that they became aware of the criteria against which the School is assessed. Thus the students had an opportunity to see if the claims of the course, in terms of meeting many UK-SPEC, could be met. In addition the criteria by which the School and its degree programmes were judged, were shared with students. For each Weekly Update students were asked to give examples of which UK-SPEC had been met.

The mark allocation of these Weekly Updates was intended to encourage both individual and group effort. As there were seven Weekly Updates, so each member of a group was made responsible for one Weekly Update. This individual was allocated a mark out of 5% of the total Design course assessment. Another 3% was assigned to the group. Weekly Updates were marked and returned together with feedback to students the week after they had been handed in. Feedback was given to each group in turn, so that each group had dedicated feedback with all the potential benefits of this. The Weekly Update was limited to two sides of A4 so that marking time was minimised and the document facilitated regular and rapid feedback.

Full attendance at all Design classes was strongly encouraged through the taking of registers and it was felt that peer-group pressure also supported high attendance rates. In the first week of the module a group essay related to sustainable development was set. This exercise gave students an introduction to the forthcoming design project. A straightforward change introduced in 2007-08 was to use Blackboard™. This served as a depository for all course documentation, background reading and allowed quick communication with the student cohort. Group size was increased slightly, from six in 2006-07 to seven in 2007-08 and 2008-09. In summary, the assessment (and % marks) for academic year 2007-08 onwards consisted of a group essay related to sustainable development (5%), an Interim Report (33%), seven ‘weekly’ updates (21% + 5%), and a Final Report and Logbook assessment (36%).

The School of Mechanical and Systems Engineering gathers feedback from students on all of its modules. This allows a comparison of student opinion on all modules. From 2007-08 the current Design module leader introduced an additional and more comprehensive feedback form for the module. The anonymised form consisted of ten questions which were answered on a 5-point scale. In addition there were four open-ended questions where more qualitative data could be obtained. Informal feedback was gathered during the course and the ongoing interaction with the different groups provided copious opportunities for feedback.

## 2. STUDENT FEEDBACK, AUTHORS COMMENTS AND OTHER RESULTS

In the years in which the Design course has run in the form of group projects there have been very few students who have failed the module. Those who have failed have not engaged and contributed to the group and have been penalised by the group. Such students have consistently

failed many other modules within the second year and have left the School or, on just one occasion, re-sat the entire year. For the academic years 2005-06 and 2006-07 informal student feedback showed that students enjoyed and felt they benefitted from many of the aspects of the group work. However, there was less enthusiasm about the caravan related projects, despite its linkage to local engineering industry and the 'prize' of a summer work placement with Explorer Group where the 'winning' design could be taken forward to be manufactured and included in a caravan. For these reasons the 2007-08 Design module was changed as outlined above.

In all academic years formal feedback was gathered from students. For 2007-08 formal student feedback showed high satisfaction with the course. From the closed questions the lecturers' interest and enthusiasm in the subject was particularly highly rated by the students. From the open ended questions students positively acknowledged the creativity allowed them in the projects as well as the topic of 'green' engineering. Interestingly the value of the Weekly Updates was also appreciated by the students who noted how this document helped them in the design process by highlighting their project's progress and encouraging them to examine their ability to meet UK-SPEC requirements that related to their project.

For 2008-09 student feedback has been even more positive. Fifty seven of these anonymised questionnaires were returned in 2008-09, and these results will be focussed on in the following sections. Students commented very positively on the module and their learning experiences. For example, that students felt that they learnt a great deal and applied engineering knowledge was shown by the following comments: 'I feel as though I have learnt more in this module than the entire 1st year'; 'improved a whole range of skills rather than just dry theory'; 'a lot was learned from the achievements and failures'; 'it was good to apply what we have learned'; while another student felt a positive aspect was the 'application of knowledge gained from past years'.

Confirmation that students felt that they enjoyed the learning experience, and recognised that it was different to 'traditional' lectures was shown by the following remarks: 'very enjoyable, made learning not a chore'; 'enjoyable to put knowledge into practice'; 'good fun therefore a better atmosphere for learning'; refreshing to not always have lectures, but to learn ourselves'; 'enjoyable learning process'; and one longer statement included 'taking the project into our own hands allowed the team to explore the project in many ways and determine our objectives and achievements. Again this allowed a more advance learning into the project, whereas if it was taught, then the opportunity to 'explore' would not be permitted'. Students also acknowledged that 'research played a huge role into finding solutions, and with all this research provided self learning which probably could not have been absorbed if it was taught in lectures etc'.

Evidence that students felt that they had experienced professional engineering was supported by the following comments: 'the course gave the feeling that I was working as a real engineer'; learning professional engineering skills'; 'it was a good way to get introduced to professional engineering' and one team described themselves as 'a group of young future professional engineers who now have experience in managing long-term engineering projects as part of a team'. That students enjoyed the hands-on aspects of the module was shown by the following comments: 'we actually got to do stuff'; 'a lot has been learnt through the duration of the entire project, knowledge which could not have been conveyed from lecturer to student other than through (this) type of practical learning'.

Evidence that students valued 'green' and realistic projects was clear from the following comments: 'applying engineering for relevant project (environmental issues)'; 'able to apply this course to real life' and 'it was refreshing to actually apply engineering knowledge to a real application'. That the opportunity of creativity was recognised and appreciated was shown by the feedback: 'encouraged imaginative thinking' and 'creativity that you do not get from any other module'. Additional positive comments included: 'made new friendships within the group'; 'the course was run in a professional manner and we were treated as such'; 'money to spend/be trusted with'; 'whole process from design concept to testing showed continuity'; and 'budgeting and component sourcing from companies'. One student commented at length in his log book as follows. 'Design has been a truly challenging project, involving lots of engineering tasks, decisions and justification in order to make the project a huge success. With the involvement of designing, manufacturing, as well as cost management and time keeping, it prepares what might be experienced when in industry. Not only has this project been an eventful learning process, but also invaluable skills and experiences have been obtained, such as working with others in a team, to organising and contributing'. He continued: 'What has been particularly interesting and enjoyable is the designing of the turbine itself. It allowed myself to express the creative and innovative side of me and really applied the ideas. Nothing is more rewarding than to see what you've created in actual use, and to see it working is overwhelming'. Such very positive comments have led the lecturing staff to judge the module a great success.

From the ten questions that were answered on a five points scale, the longitudinal student answers to the question "Your overall rating of teaching on the module" for the academic years 2007/08, 2008/09 and 2009/10 are shown in figure 1. There were 52 responses in 2007/08, 57 in 2008/09 and 82 in 2009/10. The increasing number of responses in 2009/10 was due to the fact that the student cohort increased in size that year and also that attendance at the feedback lecture was more strongly encouraged. As can be seen the overall responses were positive and have improved over time, with the slight 'tail' removed in the latest year.

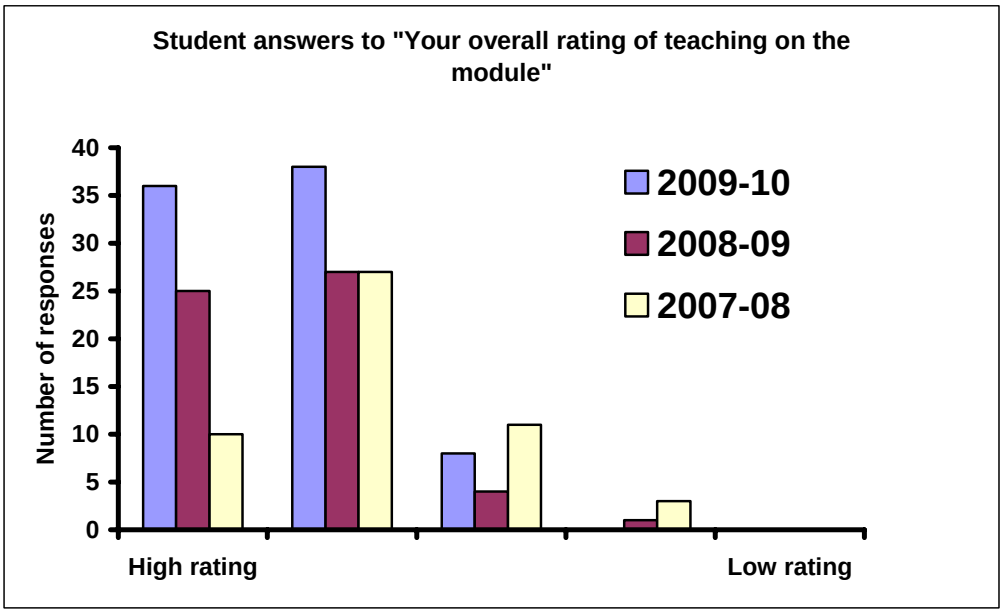


**Figure 1 student feedback over three academic years to the same question**

Attendance was monitored at all classes and was always above 90%. This success was felt to be due to a combination of factors. Firstly that an attendance register was taken and groups who had individuals missing were asked to explain why this was. Attendance and professional behaviour was linked to success as a future engineer in business rather than just attending another class. Secondly it was felt that students enjoyed the course so much that they wanted to attend, a feeling that was compounded by positive peer-group pressure. In terms of academic quality, it was judged that the students' designs were of a high standard. From the 2007-08 cohort, one student took a year out to take advantage of an industrial placement as he had been so inspired by his group's design. Upon returning he is developing the design, of a thermostatic valve for domestic radiators, for manufacture.

## 3. DISCUSSION

For the academic years 2005-06 and 2006-07 the students all passed but there was limited enthusiasm for a caravan based design projects. For 2007-08 and 2008-09 this was countered by a 'green' engineering theme which it was anticipated would interest the students, while creativity in the design process was maintained by offering open-ended projects. Formal written feedback from the students showed that both creativity and relevance were achieved. For 2007-08 laboratory space was requested for term 2 to allow models of the students' design to be made. Unfortunately, this did not happen due to space and timetable restrictions. However it did occur in 2008-09, over both terms, and the students responded positively. If a student contributed to the group then it was unlikely they would fail the Design module. The few failures were due to a low allocation of marks from the group, through the peer-moderated marking scheme. All failures that occurred were associated with students who performed very badly across all their second year modules, not just Design. The peer-moderated marking scheme was felt to be just and to work well, supporting literature which suggests that it can give a fair assessment of student input into team projects (Willmot et al., 2008).

There is a great deal of literature which supports the use of project based learning (Abdulwahed et al., 2008). Such project based learning is said to be a constructivist pedagogy practice and to offer a student centred approach (Abdulwahed et al., 2008). Moreover the real or quasi-real aspects of the projects are said to offer relevance to students (Abdulwahed et al., 2008). Similarly there is a wealth of material to support the use of challenge based or enquiry based learning (Bramhall et al., 2008; Powell et al., 2008) in which students are given greater responsibility for their own learning. Feedback from students taking the Design course indicated that they enjoyed this challenge of designing, building and testing their wind turbines, and they felt they learnt more from this process than they would have from 'conventional' lectures. Additionally the benefits of hands-on work to engineering students have been recognised (Lambert et al., 2008) and this opinion was supported by student feedback from the Design module.

One issue, given the high staff workload, is the long-term viability of the course. While the authors recognise the high workload they are enthused by the positive reaction of students to the course and to their input. Such intrinsic rewards justify, in their opinion, the high workload. They also feel that the module has been, and continues to be, developed through a team approach

and with input from each member. Therefore, while losing one current member of staff would be challenging, it would be hoped that any new member of staff would quickly appreciate the ethos of the module and bring their own perspective to this positive environment.

In the Design module, lecturers see themselves primarily as facilitators (Lambert et al., 2008) although some lectures are given in which technical information is offered. For engineering students, the value of being an experienced and skilled team player as well as being a good engineer has been recognised (Steiner et al., 2008). It is felt that the experience gained during the Design course will help students in this respect. Moreover the shared learning aspects of group working should be appreciated too (Powell et al., 2008; Johnson, 1999). It is felt that the Design module has been improved year on year, with parallel increases in student satisfaction and student learning. Part of the ethos of the module can be supported by comments taken from the 2005 'Educating Engineers in Design' publication from the Royal Academy of Engineering: *And what do we need to teach? We don't. We need to give the opportunity to gain experience and awareness in multi-disciplined team environments and let the confidence of youth loose on a prepared world. What can we give students in a university department? Experience of working in multidisciplinary teams working on realistic projects.* (Royal_Academy_of_Engineering, 2005)

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