IE&PDE 2004, Delft University

Escaping the Straightjacket of Engineering Education

PRN Childs, LA Robinson and RK Stobart
University of Sussex

Abstract

Engineering education in the United Kingdom might be characterised by a conservative and pragmatic approach. It has developed from the approaches developed during the age of enlightenment and industrial revolution and has since been subject to a number of reviews and evolutionary changes. Engineering degrees in some cases have been taught by a combination of distinctly identifiable modules, which, despite good intentions and encouragement by accreditation bodies, are rarely explicitly interlinked or interrelated.

The use of a virtual learning environment to support a problem based learning approach to facilitate the acquisition of a wide range of interdisciplinary skills is explored within this paper. Students are asked to design a transmission system for a compressor by an OEM (original equipment manufacturer). The activity requires marketing, business planning, project management, specification, conceptual design, detailed design, preparation for manufacture, team-work and liaison with a number of individuals and organisations. The mechanism of running the project is described here along with the methods employed for persuading sceptical colleagues to embrace newer ways of providing education.

1 Introduction

Engineering education in the UK finds itself in the context of a declining national industry. In the 1960s engineering activity contributed approximately 40% of the UK GDP; by 2002 this had fallen to approximately 17%. Engineering education in the UK has seen a number of significant changes stemming from the Finniston report and more recently the attempt encapsulated in SARTOR (Standards and Routes to Accreditation) to improve the standard of those graduating in engineering disciplines. The popularity, if such a term can be used for engineering courses in the UK, is mixed. Faced with declining applications some institutions have developed their curriculum by offering degrees in motor-sport engineering, design and multimedia and digital systems. An alternative and in some cases complementary approach has been to use the research expertise of the host institution as a selling feature to prospective undergraduates. Such degrees and approaches have offset a sure decline in applications to subjects such as mechanical, electrical and electronic engineering.

Education in the UK has also seen significant changes. By the 1950s techniques such as the use of board and chalk were widely being haled as archaic following the advent of television and the innovative techniques developed by the OU. In their place came interactive, project based and case study learning. Higher education has been significantly expanded so that now 43% of the population is involved in learning at higher education level. Subjects such as English literature, psychology and media-studies are highly popular and traditional subjects must compete with these in their attempt to attract students. It is within the context of a declining engineering industry, increased competition and higher student expectations and aspirations that the challenges for a newer approach to the provision of learning in a traditional engineering area were set.

Engineering requires a refined set of analytical skills alongside a practical sense of what works. Recent technological developments in design processes mean that engineers will need

to do progressively more work by computer alone without the benefit of creating and testing physical prototypes. Learning of engineering processes is therefore a major challenge in that it must accommodate this move from the use of physical to 'virtual' or computer-based design processes. As well as using specific computer-based design tools it is vital that students are given the opportunity to develop competence and become comfortable generally working in the virtual world as an integral part of their learning experience. Graduate engineers are increasingly being required to work on design problems as pro-active professionals in multi-disciplinary project teams. So as students they need to learn how to deal with problem-based situations, develop the research skills to draw on a wide range of resources and communication skills to work effectively as part of a team. Learning and teaching approaches need to be adopted, which are commensurate with achieving these aims. Using ICT to support team-working processes is another aspect of preparing students for the real world.

The teaching of engineering at Sussex has tended to be traditional in nature. The use of conventional lecture facilities, with calculation-based exercises discussed during large "problem classes" has been the norm. However the final year project has proved to be popular and successful means of consolidating course material. This experience suggests that a closer relationship between formal tuition and the related problem solving would provide a more effective learning experience. This current offering is ad-hoc and needs a systematic approach to integrate learning methods into the wider curriculum.

The project plan described here directly addressed all of these issues. By implementing a problem oriented teaching strategy utilising the virtual learning environment we aimed to develop greater independence in the students while at the same time giving the opportunity to develop their group-working and computer-based research and communication skills. At the outset it was envisaged that benefits to staff would include a redistribution of teaching load to a wider range of faculty and less pressure on general teaching space. The course lecturer would released from the lecturing task and be able to relate to students through the more useful means of questions, answers and explanations. It was viewed that this a better feedback mechanism as the students move to independence in a more fulfilling learning environment, experience team working, improve communication skills and gain a stronger commitment to the learning objectives.

The Project aims set by the course team comprising a representative of the University's Teaching and Learning Development Unit, the course lecturer and an academic colleague operating in a consultative role were to:

- Introduce a problem-based approach for these courses.
- Reduce dependence on lectures and provide learning resources via web.
- Focus support for the students, working independently and in small groups, on a combination of face to face tutorials and asynchronous online discussions.

The Specific Objectives of this project were to:

- Stimulate development of team-working skills and a pro-active attitude towards problem-solving as a simulation of the typical team-working experience of engineers and designers in industry
- Provide use of an online environment as an integral part of students learning experience to improve their skill and confidence in working in an online environment
- Develop students as independent learners
- Create an interesting, exciting and motivational learning experience
- Re-energise the relationship between personal tutors and their tutees

- Get students to engage with fundamental design questions in a practical way
- Provide a competitive but fun environment for students to experience giving presentations as preparation for their more formal 'Design Seminar 'presentation later in the year and for them to get feedback on the effectiveness of their presentation from their tutors and peers.
- Produce a set of web-based resource packs for learning about the design of: bearings; Gears; Clutches & Brakes; Shafts
- Evaluate the effectiveness of this approach to teaching and learning in this area.

The learning process and the support material were firstly specified, then designed in consultation with the Educational Technologist and Academic IT Support Manager. The specification covered: pedagogic and overall course design; operation of the VLE (WebCT) and development of associated faculty IT skills; the design of web-page templates; the dissemination of information about on-line learning to students and evaluation of student and faculty experience. Testing proceeded, admittedly late, with a small team of students. The project team, the course lecturer and a number of colleagues monitored first use and provided the needed feedback for improvement. It was intended to support the development from the LTSN and in particular the Engineering branch located at Loughborough University.

The resources required comprised:
People
- Project team: Richard course lecturer, one academic acting in a consultative role, a Year 4 student programmer , an educationalist
- Testing group: A former student
- Teaching team: Personal tutors, a CAD manager
- Technical support: a CAD manager

Software
- WebCT; web-browser (IE); FrontPage; ProEngineer

Materials
- Content derived in part from a recent textbook (Childs (2004))
- Specialist design spreadsheets written by an academic (Childs (2003))
- Failure Modes and Effects Assessment guidelines (SAE)

An aspect all too frequently overlooked in curriculum development is project planning. The timetable set out by the team at the outset is given in Table 1.1. This timetable was developed to allow the course to be taken in the winter term of Year 3. The development phase thus occurred through the preceding summer.

Table 1.1 Project timetable (RS= course lecturer, PC= academic consultant, LR= educationalist, GM=programmer, TB= computing administrator, NC= administrative assistant, LC=timetabler)

Date done by	Activity	People
June to mid-July	Meetings to establish overall course design & agree project plan	PC;LR; RS
30/7	Specification of web-based teaching materials	PC; LR; RS; GM
30/7	Registering & set up of WebCT course	TB

31/7	Training of project staff on webCT	LR
1/8	Specification of detailed design WebCT course components	PC; LR; RS
1/8	Development of student briefing pack	PC; GM
29/8	Development of web-based teaching materials	GM
29/8	Development of student WebCT training materials	LR
3/9	Briefing personal tutors about course & their role	RS
3/9	Staff development in facilitating group working	RS; TLDU
3/9	Training of personal tutors in WebCT	PC; LR; RS
5/9	Organisation of presentations	NC
5/9	Timetabling for meetings and presentations	RS; NC
30/9	Design & development of evaluation instrument	PC; LR; RS
Week 1 Term 7	Training of students on WebCT	PC; LR; RS' GM
Week 8 Term 7	Delivery of evaluation instrument	LR
Week 11 Term 7	Analysis of data collected	LR; LC
Week 11 Term 7	Evaluation of tutors' experience	RS; LR
Jan 2004	Analysis of feedback	PC; LR; RS
Feb 2004	Action plan for changes drawn up	PC; LR; RS

2 Teaching & Learning Strategy

It was decided that students would work in small teams using the web-based resources to learn specific design principles in order to develop a 'transmission design' in response to a brief. They would receive feedback on their preliminary designs from their colleagues at a design review part way through the course and present their final design formally to the 'customers' at the end of the course.

Personal tutor groups would work together with a 'design consultant' (their personal tutor) to produce their solution to the brief. As a team they would be required to:

- Meet regularly and communicate as a team using WebCT to facilitate and record this
- plan their approach to the learning required
- identify and use the relevant resources in WebCT to learn about design of various components
- negotiate roles in the group in relation to the presentation
- plan & design their presentation
- review another team's design
- deliver their presentation to the 'customer' as a team

The design consultant (personal tutor) for each group was intended to act as an advisor to the team whenever requested. They would help students identify the key knowledge and issues associated with answering the questions and guide students to and through the web-based learning resources where necessary. As the personal tutor they would have a role to play in facilitating team-building and monitoring students' individual progress with the task and team working. It was intended that regular meetings of the team and the design consultant were to be timetabled, however the students themselves would take responsibility for managing and scheduling activities as apart of the team-working process. Teams were allowed to draw on

the ‘design consultant’ at any time in addition to the timetabled face to face sessions, however, any additional time will incur a ‘notional’ cost to the project. It was recognised that facilitating group-working may be a new role to many tutors and the department will provide staff development and resources in this area in preparation for this role.

2.1 Learning Resources:

A set of learning materials were prepared as web-pages to cover the subjects of: bearings; gears; clutches and brakes; shafts and other machine elements. The proposed web materials were designed from both a pedagogic and presentational perspective. The course had already been progressively transformed to Word documents for notes, and Powerpoint slides for lectures. While there was significant work to be done to transform this material, it was at least already available in machine compatible form. In total the time required to produce the 2000 web pages in the VLE from the existing files was approximately 150 person hours.

Each resource block included:

- an explanation of the nature of the problem
- theories & diagrams
- worked examples of calculations
- Failure modes and effects assessment (FMEA) guidelines
- Specialist design spreadsheets

Other documents made available in WebCT included:

- course description,
- project brief,
- design review guidelines
- customer presentation brief
- assessment specification
- readings about group working
- timetable
- proformas for deliverables (i.e. design review feedback & action plan)

There was course discussion area – where any team member was able to ask questions or seek clarification. It was intended that this would be monitored on a daily basis by course tutors. This did not in reality occur and monitoring instead was on an ad-hoc basis or following a complaint or dose of frustration from a student or colleague. Each team was given a private discussion area – this could be used for communication among the team. There was no expectation that the design consultant would access this every day, however they would be contactable by normal communication methods ex gratis visit; phone and email.

The structure of the design review in Week 6 was such that

- each team reviewed another team’s design
- both design consultants should have been present at the meeting
- the meeting was chaired by the reviewed team’s design consultant
- pairings of teams were randomly selected and all took place during the same timetabled two hour block during week 6
- 20 mins presentation & questions; 15 mins: reviewers feedback; 15 mins: reviewers - write up review feedback proforma & reviewees - write up action plan
- guidance notes on the review process were be provided for both the reviewing team and the reviewed team;

- the review was chaired by the design consultant of the reviewed team and who acted to ensure that the meeting ran to time and that the feedback record and action plan forms were completed by the end of the session and a copy of each is lodged with the relevant administrator.
- the design consultant of the reviewing team mentored the reviewing team and guided the process.

Presentation to customer: (Week 10)

- these will take place at a whole group 'event' in week 10
- customers will be HOD and visitors from industry
- take place in formal surroundings (eg. new conference room)
- involve the whole course group
- at the end of the session the customers will award the contract to one of the teams
- the 'winning' design will be showcased by the department on WebCT

Formal feedback will be given by the peer group during the 'design review' process. Each reviewing team will complete a proforma recording their feedback and grading aspects of the design from unsatisfactory to excellent. The reviewed team will draw up an action plan for revision of their design based on the feedback given and record this on a proforma. Both forms will be completed within the review session and a copy submitted to the school office. At the end of the course each team will submit their group design and present it as a group to the 'customer'. Summative assessment will be in the form of an individual detailed analysis report explaining and justifying/critiquing the choices/decisions embodied in the group design. It will include a reflexive analysis of the action plan, its implementation and the group working process.

Table 1.2 Teaching Timetable

Week	Activity	Support provided	Deliverable
0	Staff briefing & development session		
1	Brief delivered to students by email in WebCT Work through team-working readings on WebCT	WebCT Orientation class ProE skills workshop	Logon to WebCT & post message to the group
2	Identify key knowledge and issues required Plan team-working process Work through resources	F2f Team meeting ProE skills workshop	List of team Roles to be posted on WebCT
3	Work through resources	ProE skills workshop	
4	Work through resources	F2f Team meeting	
5	Work through resources		

6	Work through resources	F2f Team meeting	*Design Review*
7	Work through resources		Review Feedback /Action plans posted on WebCT
8	***Independent working on Design***	F2F Team meeting	
9	***Independent working on Design***	Complete cs evaluation form on webCT	Presentation title & team roles to be posted on WebCT
10	***Presentations to Customers***	Whole group Event	**Design Submission & presentations**

3 Brief

The brief presented to the students was as follows. A small and medium enterprise (SME) company has investigated the potential market for a small electric motor driven air compressor. The market analysis has confirmed the requirement for an 80 m^3/hour, 7 bar air supply driven by a 5 kW electric motor. Preliminary design has already resulted in the selection of an electric motor, with a synchronous speed of 2850 rpm, and the piston and cylinder and associated components for a reciprocating compressor. The compressor design speed is 1500 rpm. A general arrangement for the compressor concept is given in the figure below. The choice of transmission and its detailed design is yet to be undertaken. The SME company concerned does not have the resources in-house to undertake the detailed design of the transmission and wishes to offer this work to a team of consultants. In this course, you form the design team of consultants concerned.

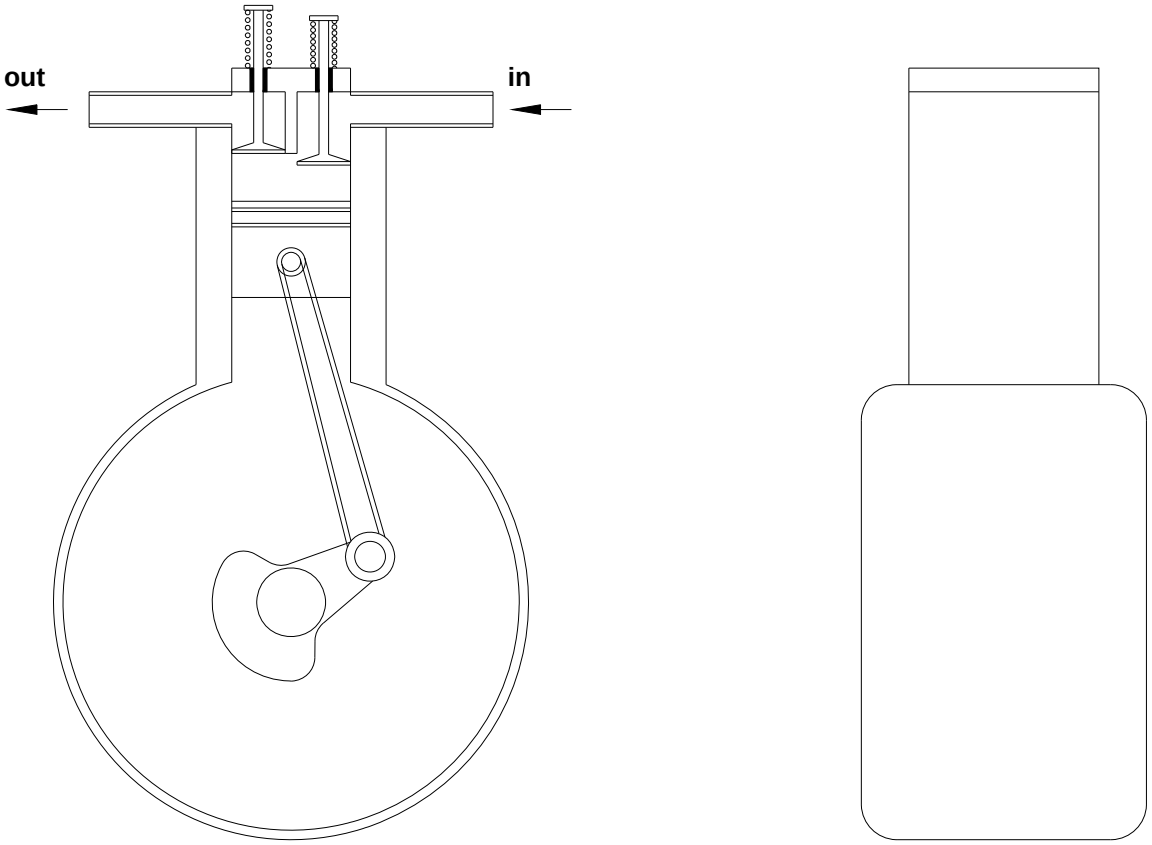


Figure 1: Compressor schematic

A detailed product design specification is yet to be developed. Once available conceptual arrangements for the transmission and detailed design of the transmission should be undertaken. The design teams tendering for the work will be required to develop and produce the detailed product design specification and conceptual solutions prior to a design review, which will take place in Week 6 of term 7. Your design team will also need to present the detailed design of the transmission in Week 10 of Term 7. In addition, in Week 10 of Term 7, each member of a design team will need to submit an individual report covering the design brief, product design specification, conceptual solutions, and detailed design of the chosen concept. The SME company is requesting that the detailed design submission include a ProE model of the design.

You will be expected to work within a team, defined by the course leader. The team will be expected to:

- Meet regularly and organise themselves and their work
- Plan work and allocate tasks and roles
- Record their working processes and decisions
- Use the resources in the VLE as well as other material to develop a design to satisfy the brief
- Plan and present their design at a design review in week 6
- Plan and present their detailed design to the customer in Week 10

As an individual you will be expected to:

- Work as an equal, professional, active and responsible member of your team
- Contribute to the team's design
- Submit an individual report on the design & process.

Deliverables:

- Design review: Your team's project planning, detailed product design specification, conceptual solutions and evaluation will be presented by the team in Week 6.
- Detailed Design Presentation: Following the design review and in light of the feedback given you will need to develop the detailed design of your preferred concept. Your team will formally present the detailed design of the transmission in Week 10 of Term 7.
- Individual Report: In addition, in Week 10 of Term 7, each member of a team will need to submit an individual written report (2000 words) including supporting pictures covering the design brief, detailed product design specification, conceptual solutions, and detailed design of the chosen concept. The submission should address project planning, manufacture, costing and evaluation issues. The SME company is requesting that the detailed design submission include a ProE model of the design. In addition to any illustrations of this used in the report and presentations, the ProE file of the design should be submitted in a CD pouch as an integral part of your individual report.

4 Student Experience

The venue (University's newly refurbished conference facility) was excellent in conveying the right atmosphere for the event and turnout was high. Over 96% of the students were present on time and extremely well turned out – most were in suits. Students were attentive through all the presentations – the atmosphere was competitive with respect to the design solutions – many comparative comments about the technical merits of the designs being presented were being made in the audience around me as each presentation was made. There was a lot of nervousness in the audience before people went on stage but this was not evident once they were presenting. Some of the presenters were not aware of the need to stay near the microphone although all dealt fine with using the mouse to advance the powerpoint presentation. The quality of the slides was excellent overall as was the style of the delivery. The proceedings were chaired in a masterly way by the chair of the 'Customer' panel the timekeeping was meticulous and this certainly contributed to a very 'professional and polished event.

It was evident from both the perspectives of educationalists and engineers that the amount of learning that had gone on during the project was immense. All of the groups described the way they had organised their teams, how they had planned and tackled the problem brief (including methodologies for approaching the design task); the decisions they had focussed on and what they had had to find out in order to make them. Some had even reflected on the effectiveness of their approach at key stages in the process and had made changes to their team working in response to this. The best groups played to the strengths of their team members and had obviously worked cohesively as multi-disciplinary teams. They all spoke confidently on the technical detail of their designs and many spoke convincingly of why their product was superior. Generally they stood up to questioning well when put on the spot and it was evident in most cases that every member of the group had been equally involved in the production of the design.

To summarise there was lots of evidence of:

- Deep learning
- Active and independent learning

- Synthesis of a diverse range of subject knowledge and practice – beyond that covered by the content of this course
- Strong team-spirit and effective team-working
- Intelligent analysis of each others designs
- An enthusiastic and professional attitude towards the project; the presentations, the customer panel and each other

Following on from the final presentations, a verbal feedback session resulted in the comments reported in Tables 1.3 and 1.4.

Table 1.3: Feedback from students. RS=course lecturer

Students	Course lecturer
We didn't know what was expected – you need to be more specific; we put all our effort into this course; we have learned a lot from it but it was more stressful than other courses. You need to be more specific about how much time we should spend on it; look at how the groups were divided and divide them more evenly in numbers - smaller groups could see that larger groups were doing more so they felt stressed by that and tried to do more too.	RS said they would take the group sizes into account when marking (but it wasn't taken into account by 'customer panel'); You wouldn't know how long to spend on something in Industry you just have to take a professional approach. We could offer a time-management skills course in week 1.
: It was good working in a team environment but what about the individual report – what happens when team tasks have been done by individuals how do you report on something you didn't do and how will you be marked on that?	RS: we will mark principally on your own contribution, we will evaluate this from your approach, you have to trust us to apply the evaluation criteria fairly
it would be good if we'd had these criteria in advance so we could strike a balance in terms of what to include – do we have to include everything?	RS: include what are the successes
what is the difference between the three courses? – you said there were different marking criteria for each but that isn't evident from the documents on WebCT	RS: the differences are quite subtle but they will draw out different emphases
you need to explain from the start how important it is that everyone must put in equal effort all the way throughout the project – good report writers could feed off work done by others and that isn't fair; timetabling group meetings would help and give a route through which the project manager could communicate to faculty that someone isn't pulling their weight.	RS: you could include the group report as an appendix and refer to that in you individual report;
the product designers concentrated on the casings and identifying off the shelf components rather than the calculations for the components themselves is that the way	RS: yes often it is

industry is going?	
you need to take measures to educate the supervisors (Design Consultant-Personal Tutors) some were much better than others – some were more able to encourage and give subject guidance; some seemed to know nothing about the project – one group nabbed Peter Childs because they knew he had the answers	*need for timetabled time-slots*
One group saw their Design Consultant once and he didn't know what it was about at all; others had trouble getting everyone to meetings; often WebCT was down; a communication route is needed for when things are going wrong or not working and somewhere you could access computers and have a group working space.	

Table 1.4: Feedback from students. RS=course lecturer

Course lecturer	*Student response*
RS: WebCT Chat Room – he was online for answering questions every weds 6-7pm but not much use made of this – perhaps the time was wrong?	Yes – more times needed not just Weds; needed more feedback on how they were doing; preferred meeting f2f as you can't show what you have done on the web-site only do text chatting
RS: what's the best way to interact?	WebCT too slow; you can't hear what other people are saying; when you are acting as competitors you don't want to share information

Conclusions

The planning discussions and generation of the VLE required an additional 400 person hours over and above the time that the course would have required, had it been left as a lecture presentation only course.

The combination of PBL and use of the VLE described provided an environment within which students worked considerably harder than in previous years where similar learning material had been presented. The student work was, in the words of one of the external industrial judges, 'at worst satisfactory, at best absolutely stunning'. This raising of the overall standard is surely worth the additional effort that went into to generating the VLE that should, with relatively minor modifications be useful for three further years.

References

Childs, PRN. Mechanical Design. 2nd Edition. Elsevier, 2004. ISBN 0750657715.