Professional engineering design skills development

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• Tutor in Study: Greg Rowsell, Senior Lecturer in Engineering Design, Department of Engineering, Harper Adams University College

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Study Author: Dr. Richard Dales, RD Research Consultancy
Tutor in Study: Greg Rowsell, Senior Lecturer in Engineering Design, Department of Engineering, Harper Adams University College
Subject Area: Engineering Design

This case study has been developed from data gathered through interviews with the tutor, a student focus group and observation of the competition event.

Background

This case study reviews a year long, group-work project module: EI007 Engineering Design – Human Powered Off Road Vehicle (HPORV) at Harper Adams University College (HAUC). The aim of the module is for student teams to design and manufacture vehicles that ultimately are tested in a competitive, multi-trial event on a challenging off road course. The module is taken by all second year engineering students regardless of their degree programme and so allows students from a range of different backgrounds and career trajectories to work together. This year the second year cohort comprised 55 students, who were allocated to six teams of eight students and one team of seven. The respective programmes that the students were taking ranged from MEng/BEng/BSc degrees in Agricultural Engineering or Off Road Vehicle Design, BSc in Agricultural Engineering with Marketing Management through to Foundation degree (FdSc) in Agricultural Engineering. Students were not grouped on the basis of previous performance and a balance of those students studying Agricultural Engineering and those studying Off Road Vehicle Design was sought for each group. The module is led by Greg Rowsell and its success centres around a team approach to developing and delivering the module that incorporates David Allan (industrial manufacturing), Dr. Ianto Guy (mechanical and off road vehicle engineering) and David White (Engineering Mechanics).

The module is well structured. On week one of the course the students receive an introductory presentation, are allocated to their teams and provided with detailed documentation (the Module and Task Information documents) that outlines the timeframe of weekly activities and explains the nature of the task. This project brief clearly indicates what is expected from individuals and teams, the design constraints imposed and the assessment processes involved. The regulations attached to the design brief for the HPORV are quite restrictive and include:

- the vehicle must have four rotating wheels that are all in contact with the ground when on a flat surface and that each wheel must be capable of bearing at least 15% of the total vehicle weight
- the vehicle must derive all of its motive power from one or more human operators and all the drive power must be transmitted via a mechanical transmission to the wheels
- the vehicle must be capable of mechanical steering with a turning radius of ≤ 3 metres and be fitted with a mechanically actuated braking system operating on at least two wheels and capable of stopping and holding the maximum gross vehicle weight (MGVW) on a 30° slope
- the maximum empty weight of the vehicle is 50kg and this needs to include a seat for the operator; safety aspects such as operator harnesses, roll over and moving part protection; front and rear towing points; a towing rope; and a repair kit. When more than one operator is included in the design then an additional 25kg MGVW allowance is made for each additional operator. Penalty points at the rate of 5 points per kg are incurred if the weight allowances are exceeded.

The students are shown the off road course and given the details of the trial stages that their vehicle will need to negotiate. There are ten stages that involve a range of obstacles and tasks, which will be timed. These include ascending, descending and parking on steep slopes, traversing various terrains, including a sand pit, and over obstacles such as concrete blocks and iron girders, as well as a ‘see-saw’, where specific wheel and axle dimensions are crucial. The course is delimited by bollards and tape with the
beginning and end of the various obstacle stages indicated by gates of paired stakes. In the competition event, vehicles are not permitted to touch any of the course markings and once within a stage the vehicle operators are not allowed to touch the ground. There are ten points available for each obstacle and penalty points are incurred if any of these conditions are breached, or if there is any mechanical failure within the stage.

By the end of week one the students have a reasonably clear understanding of what their vehicle will need to achieve and they are required to produce a ‘problem definition’ for week two. Each student then has to generate six different annotated concept sketches and the students are encouraged to be innovative in the production of these initial designs. During week three each team evaluates their concepts and distils their individual ideas into three team concepts. In week four each team presents their main design concept to a formal review board of the lecturers involved with teaching on the module and the feasibility of the designs is critiqued. The two remaining concepts are reserves that would need to be reviewed, if the first one fails to convince the board. The review is assessed with 50% of the marks going to the feasibility of the concept and the remaining 50% split between the quality of the supporting documentation and the quality of the presentation. The final review mark contributes 15% to the overall module mark. Basically, the process is emulating industry practice and the students are seeking to justify their concepts and gain permission to take their concept forward to the detailed design drawing stage. The teams are self regulating and establish their own leadership and management roles. Additionally, once the basic design concepts are accepted, then each student within the team will take on the responsibility for developing a specific component of the design.

Supporting lectures are concentrated during the early parts of the module. An ‘independent study week’ in the first term is commandeered for the module and during this week a series of guest lectures is provided on topics such as gear ratio calculations, stress analysis and design aspects of steering, chassis and suspension systems. Additionally, tutorials are provided on 2D drawing and 3D modelling. These are all designed to assist with the detailed vehicle design process.

In week ten the student teams have to submit a technical report that is a summation of each student’s contributory section based on their defined role in the team. This report is assessed and contributes 15% towards the total module mark. Also in week ten the teams present their designs for critical scrutiny by a review panel of staff, invited guests from industry and the HAUC Finance Director. The students obtain feedback from the panel and gain confidence in their ability to justify their designs and costings. The presentations are assessed and this ‘gateway’ activity contributes a further 15% towards the final module mark. A short video clip of some of the presentation activity at the previous year’s design review event can be observed at the following URL: http://www.harper-adams.ac.uk/press/article.cfm?ID=3064

Once the teams have obtained approval from the design review panel they then need to prepare a full set of working drawings, a ‘build book’, for their vehicle by week 13. Once this has been accepted the construction phase can begin from around week 14. The teams have two hours timetabled in the workshops each week, so the aim is that the vehicle should be able to be constructed within 12 hours. Each component or section is produced in turn from the drawings. Inevitably some components generated in this way will not function adequately and will need to be re-worked and the drawings revised. Once the vehicles are completed there is an assessment against the product specification and a vehicle safety check. Here again 15% of the module marks are available.

In the trials competition, each team attempts to power its vehicle through each of the ten stages in turn. The winners are the team with the least penalty points deducted and, in the event of a tie, the team completing the course in the shortest time. The scores achieved during the trials competition contribute towards 20% of the final module mark. A video clip showing the previous year’s teams competing in their trials competition can be observed at: http://www.harper-adams.ac.uk/press/article.cfm?ID=201056. The final 20% of module marks are available for individual project evaluation reports. These should be ≤1,000 words and should critically review the chosen solution, methodology, contributions of the team etc. as well as suggestions for change, if the exercise were to be repeated.
Reasons for introducing this teaching method

The first year engineering programmes at HAUC are largely theoretical, while the final year programmes involve a lot of ‘real world’, problem-based industrially-led activities. It was recognised that this was a significant transition and this second year module was developed as a way of introducing project based team working “but with a safety net with us there […] to walk them through it […] to give them the chance really to make mistakes and partly to raise that standard before they go out into industry.” The module has been running for around six years and is constantly evolving, through capitalising on the expertise and experience of the staff involved. Initially it used a teaching heavy, textbook-type approach. It was decided that design reviews and ‘gateway’ checks needed to be introduced to reflect the processes in industry and the vehicle competition has been brought in as a motivational aspect. The staff now take a lot of time with the students between the design reviews assessing their designs, looking at their calculations and suggesting the sorts of practical testing they should be thinking of doing to provide the relevant data to input into their calculations. This work with the students relies on the knowledge, skills and experience of all of the staff involved in the module but it has meant that these staff are providing more of a supportive role in getting the student teams to strive for continuous improvement through design iterations. In order to get more theoretical teaching back into the process, re-usable learning objects are being developed, in conjunction with the ASPIRE Centre, to provide exemplar material, case studies and tutorial videos. This catalogue of learning objects will allow students to access the materials when they want and learn at their own pace, leaving the academic staff to provide the face to face practical engineering support.

The module’s relation to other second year modules is also evolving and the aim is to make this the spinal core module for the second year, with the other compulsory second year technical specialty modules aligned in such a way that they feed their technical capabilities to the students at the appropriate time. This would free up the time spent lecturing on technical specialties within the module and give more time for creative design activities. Additionally, there are plans to include some team building exercises into the early stages of the module.

Lecturer's perspective

Greg feels that one of the major benefits of the module is the ability to teach problem-solving skills in which suitable approaches are used at the appropriate time. He cites the example of chassis design for the HPORV, where he feels it would be inappropriate to use a 3D computer-aided design (CAD) system for the early stages of this process. Instead, the best way to explore this is to model a chassis using paper straws until an effective structure has been found. Then the design can be put into the CAD software to refine the design and develop a detailed specification. The teaching process within the module is also used to try to eradicate the commonly made mistakes made by students. For example, CAD designs that either generate dimensions at accuracies that are not achievable in the workshop, or that use material dimensions that are not available from standard suppliers. Making students aware of these issues allows them to progress from having purely academic competencies towards becoming fully technically-competent engineers. This is a major aim of the module, to develop students that are capable of functioning in industry.

Students’ perspective

The students appreciate and readily articulate the benefits of this module: “We learned a lot in terms of planning, time management and industry ways of thinking.” They also value the commitment of staff and indicated that there was an excellent relationship with the staff. It was clear that the students were encouraged to resolve issues for themselves, both in the technical engineering aspects and in the management of their teams. The students had a mature attitude towards handling team tensions and realised the opportunities of team working: “Being in teams there was always someone who had an idea how to do something, so we could all learn from each other.”
This year the module was a complete ‘design and manufacture’ module, while in the previous year the students had submitted their vehicle designs for the workshop technicians to construct. The students were extremely supportive of making the vehicles themselves and felt that they “learnt so much more.” They also found that time constraints and workshop availability meant they often had to make components from drawings made by other members of their team and felt that this was a particularly valuable learning experience. Overall, this module gave the students immense confidence that when they went into industry they would then get it “right first time” and so not be “a financial liability.” All of the students said they had been quizzed about the module in their placement interviews. They said that this helped them because this was an area that they could talk easily and knowledgeably about despite the nervousness of the interview situation.

Issues

- As students are on different degree programmes, timetabling can be an issue. To counter this, the MEng and BEng students were grouped together as teams and the BSc and FdSc students made up the remaining teams. Even so there were issues raised by students about conflicting submission deadlines. This had the benefit of honing their organisational skills, particularly their time management.
- There can be conflicting demand for workshop time with first and final year modules and this needed to be carefully managed.
- Sourcing and ordering components takes up time. The establishment of standardised component kits is being considered as a possible way forward.
- The module is quite costly to run in terms of raw materials and bought in components. Possibly sponsorship could be sought from companies such as John Deere, JCB, Claas etc., that take HUAC placement students.

Benefits

- Students gain the ability to function efficiently and effectively in team working situations.
- Students acquire problem-solving design skills, where appropriate methodological approaches are employed. Students gain experience and confidence in justifying their designs, which proves particularly beneficial in placement interview situations where they are often asked to describe a problem that they have solved. Greg maintains that placement interviewers are keen to dwell on students’ work on this module because they have seen the benefits. The approach is developing students that are ‘industry ready’. Reports back from the employers indicate that HAUC engineering students are at a level when they go out on placement that students from other institutions achieve by the end of their placement.
- The approach has developed significant cohesion between staff and students and promoted the development of additional online pedagogies.
- The project benefits from having all second year students involved in the module. Currently, this is highly successful because of the relatively small cohort size at HAUC.
- Logical curriculum design will allow this module to form the central spine that other theoretical and technical specialty modules support. This will avoid duplication of teaching.

Reflections

Talking to the students and observing the trials competition it was readily apparent that they were thoroughly enjoying the module. There was a keenness to exhibit their acquired engineering understanding and capabilities, both through mature discussion in the focus group, or in the light-hearted banter between the teams at the relative successes of their vehicles in the off-road trials. The students had a healthy understanding of how they were learning. They knew that they were learning from the expertise of the staff; they knew that they were learning from their own efforts but that they could also learn “what works well and what doesn’t” from other teams. They also appreciated that things would go wrong and that this was “all part of the learning curve.”