Teaching Motor-racing Engineering through Real-life Projects: Benefits and Challenges

[1]V. Kosse, [2]D. De Pellegrin

School of Engineering Systems, Queensland University of Technology, Brisbane, Australia,

E-mail: v.kosse@qut.edu.au[1];

E-mail: d.depellegrin@qut.edu.au[2]

Abstract

Project-based learning (PBL) is widely used in engineering courses. The closer to real-life the project, the greater the relevance and depth of learning experienced by the students. Formula Society of Automotive Engineering (FSAE) is a fine example of a team-based project modeled on real-life problems whereby each student team designs and builds a small race car for competitive evaluation. Queensland University of Technology (QUT) has participated in FSAE-Australia since 2004. Based on the success of the project, QUT has gone the additional step of introducing a motor-racing specialization (second major) to complement its mechanical engineering degree. In this paper, the benefits of teaching motor-racing engineering through real-life projects are presented together with a discussion of the challenges faced and how they have been addressed. In order to validate the authors' observations on the teaching approaches used, student feedback was solicited through QUT's online learning experience survey (LEX), as well as a customized paper-based survey. The results of the surveys are analysed and discussed in this paper.

1. Introduction

Queensland University of Technology (QUT) was the first university in Australia to introduce a motor-racing specialization in 2009 to complement its mechanical engineering degree. This in turn, complements the activities of the QUT Motorsport team, which started participating in the Formula Society of Automotive Engineering Australasia (FSAE-A) competition in 2004, and progressed from 17^{th} place in its inaugural year, to 4^{th} place by 2009. Each year the competition attracts as many as 30-plus competitors from around the world. Practically all Australian universities that provide a mechanical engineering degree participate in FSAE-A. The competition started in 2000 and is organized by the Society of Automotive Engineers. It is interesting to note that the project-based learning aspect of the competition has attracted publications as early as 2001 [1].

In the two years that QUT's new second major has run, as much as one third of students enrolled in the Motor-racing Vehicle Design unit (ENB315), core of the motor-racing specialization, have been from overseas, mainly from European countries. Students are encouraged to join the QUT Motorsport team from year one of their undergraduate course in order to gain practical learning experience and knowledge, so that by year three they may become competent in designing race-car components. This also helps to maintain the continuity and avoid the potential significant decline in team performance attributed to 'generational change'.

Although the project-based teaching of engineering is widely accepted [2, 3], the motor-racing project and specialisation combined provides a specific advantage – it represents as close to a real-life project as is likely to be attained within the confines of a university environment.

Students not only have to find sponsors, conceptualize, design and build a race car, but they must also interact with external professionals and businesses while acquiring components and fabricating the race car. Most significantly, however, they must work in a multi-disciplinary team that includes young and mature-age students with varying degrees of work experience, not to mention students from both English and non-English speaking backgrounds. This brings some challenges that are not always easily overcome, however they form an integral part of students' learning experience and personal development.

2. Organisation of the project

2.1 QUT Motorsport

According to the Formula SAE rules [4], student teams have to build a small race car with an internal combustion engine under 610 cm^3 capacity, meeting requirements related to overall dimensions, strength and safety. Upon completion, the students take the car to competition. In Australia this usually takes places at Victoria University of Technology's vehicle training and testing facility near Melbourne. Each car must pass scrutineering, including examination on meeting formula rules, safety and noise specifications, and then participate in a number of static and dynamic tests. Static tests involve presenting the car to the judges and justifying design decisions. Various dynamic tests aim to test the performance of the vehicle both in terms of endurance and speed. It must also be demonstrated that the race car has been substantially modified compared to the previous years' cars, otherwise the team's score is penalized.

Students can participate in the FSAE competition while studying at university and up to six months after graduation. To maintain continuity and avoid drop-off in team performance, students are encouraged to join the team from year one or two. Students are divided in sub-teams (e.g. power plant, drive train, suspension, bodywork, electrical, etc.) led by senior students. While the mechanical engineering students form the core of the team, the project is truly multidisciplinary including students from electrical engineering, infomechatronics, telecommunication and information technologies, industrial design (they work on race car styling), business and accounting (one of the tests is on presenting the cost and manufacture report), journalism, creative industries and filming (these students accompany the team during competition, film it and prepare movies and video clips as their educational projects).

The academic coordinator of the motor-racing team is responsible for preparing a list of final-year projects, which includes topics directly related to the current race-car design, in addition to feasibility studies on new conceptual solutions. Most components that are not available off-the shelf are fabricated in QUT Motorsport and Faculty of Built Environment and Engineering workshops. Numerous components are fabricated using sponsors' facilities. Figure 1 depicts the QUT Motorsport workshop, which has basic fabrication equipment. In this workshop, students fabricate simple car components, carry out tacking of the chassis components (welding is often done at one of the sponsor's facilities), subject the suspension to roll stiffness tests, subject the chassis to bending and torsional stiffness tests on a special test rig developed at QUT (see Figure 2), and last but not least, carry out the final assembly of the race car and its tuning.

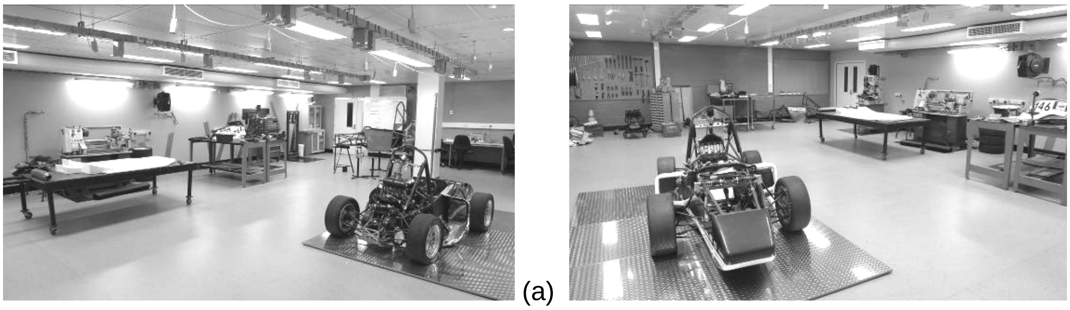
(a) (b)

Figure 1: QUT Motorsport workshop

The workshop is also equipped with networked computers for the purposes of team communication and car design. They are equipped with standard QUT software including office utilities, solid modeling (SolidWorks™), finite element modeling (e.g. Ansys™) and specialized software packages such as MoTec™ for engine management and data analysis. Sometimes sponsors provide computers with other software packages, e.g. SolidEdge™. The QUT Motorsport team also has access to supercomputing facilities available at the university for the purposes of multi-body dynamics, finite element modelling and computational fluid dynamics. A library of final-year project reports related to QUT Motorsport is also kept in the workshop for access by team members. The project reports reflect the work on the current and previous years' race cars and often include feasibility studies for future design.

Figure 2: QUT chassis bending and torsion test rig.

2.2 Motor-racing engineering second major

The motor-racing engineering specialisation (second major) was introduced in 2009. According to QUT engineering curriculum, students enroll at the Faculty of Built Environment and Engineering (BEE) and have a common first year, by the end of which they select the first major (for example, mechanical engineering) and later the second major (specialisation). The Motor-racing second major is one of four available to mechanical students. It includes eight subjects or "units". The core units are ENB315: Motor Racing Vehicle Design and the two-semester final year project whose topic must be automotive related. The remaining units are drawn from the subject areas of operations research, industrial design, tribology and engineering management. The contingent of students selecting the motor-racing major consists of both recent high-school graduates and individuals with prior motor-racing experience. The team is self-contained and elects the team manager. The team nominates the race-car drivers, which have to undergo training and obtain a CAMS (Confederation of Australian Motorsport) license. The academic coordinator oversees the project, assists with project planning and facilitates the team's communication with faculty management.

The ENB315 unit Motor Racing Vehicle Design, as the core unit of the Motor racing specialization, was developed with highly practical and hands-on focus. It is delivered by two lecturers (the authors of this paper) and includes the following topics: race-car tyre selection; brake technology; vehicle suspension design and handling; engine and engine tuning; drive train (gearing and differentials); chassis and body; internal and external aerodynamics; driver's compartment (fitting and comfort); testing and preparation of the race car for competition; safety in motor racing. The weekly contact hours include two hours of lectures and two tutorial/laboratory sessions. An essential part of the unit is the radiator design project. Each student is given individual initial data according to one of the three racing formulas: Formula SAE, Formula Ford, and Formula SCCA (Sports Car Club America). At the first tutorial students are given a briefing on radiator design and the handout, which includes formulas related to heat transfer and general recommendations on radiator design, photos of typical race-car radiator intakes, and literature sources. Students working on the radiator project have to make decisions on the number of radiators, carry out calculations to identify radiator dimensions, make recommendations on radiator shape and positioning, select components such as fans, pumps fittings, and attach sketches of the radiator design.

Of the twelve tutorial/laboratory sessions there are three sessions in computer classes on suspension geometry and kinematics, vehicle handling and working with MoTec™ software. One tutorial is devoted to race-car power plant and drive train design, whereby students work in laboratory with demo rigs of engines and drive train components (see Figure 3). The remaining sessions are conducted in laboratories where students carry out hands-on exercises. For example, students conduct experiments on determining tyre traction under different road surface conditions, identification of tire wear pattern on sectioned tyres, bending and torsional chassis stiffness, roll stiffness test using calibrated plate method [5], working with instrumentation (e.g. noise and temperature measurement), hazard identification and risk analysis, and various other experiments.

To further enhance the practical focus, team teaching is used, engaging academics and technicians with specialist background, as well as contract tutors with industry experience. For example, the team includes academics (authors of this paper) with expertise and experience in engineering design, motor racing vehicle design, computer modelling of transition processes in drive trains, machinery failure analysis, heavy machinery, machine condition monitoring, tribology; technicians with expertise in motor-racing, machinery, hydraulics, control systems. All technicians are proficient in solid modelling. Some academics hold numerous patents on novel mechanical equipment and devices. Team teaching enables different topics to be delivered by lecturers with the most expertise in the relevant area. This approach ensures the highest possible level of teaching. Guest speakers have also been engaged to make presentations to members of QUT motorsport.

2.3 Benefits and challenges related to teaching motor racing engineering

Among benefits and advantages, the following can be listed:

- The project is truly multi-disciplinary, embracing students from engineering and non-engineering disciplines. This helps them to develop multi-disciplinary and teamwork skills above and beyond the prescribed academic curriculum, and to better prepare for an immediate and productive start in industry.
- Most team members find employment before graduation owing to the unique skills acquired through the program.
- The project is highly practical and hands-on. Students design the racecar and manufacture many of the components, test and tune the car, and compete in Formula SAE in Melbourne, Australia.
- Students acquire in-depth knowledge of engineering design. To develop a high performance car in terms of acceleration, braking and handling, students use modern computer aided design (CAD), solid and finite element modeling.
- To design a race car that is reliable, easy to maintain and cost effective, students have to make sound economic judgments. Moreover, assessment items during competition include cost and business-case justification.
- To have the race car ready for competition students set milestones and apply project management and scheduling skills to meet them.
- Students foster their problem solving skills by putting into practice, in a real-life project, different creative problem solving tools that they learn in engineering design units. QUT prides itself on systematically teaching more than ten creative problem solving tools with special emphasis on Ideation/TRIZ methodology (the theory of creative problem solving).
- Students foster their information retrieval skills. In a real-life project they have to hypothesize, conceptualize, experiment, implement solutions and review the outcomes. The

learning outcome is that students acquire skills in finding things out for themselves through disciplined enquiry [6].

- Students foster their cross-disciplinary interaction skills working in a multi-disciplinary team comprising students from both English and non English-speaking backgrounds.
- In a real-life project students have to identify hazards, assess risks and implement measures addressing these risks, and also strictly obey health and safety regulations at all times. To practically address health and safety issues the QUT Motorsport team appoints one of the students as Health and Safety Manager (usually a mature age student with industrial experience).

From the above list of benefits it is evident that combining FSAE participation with engineering coursework provides not only a high quality learning experience for the students, but is also highly beneficial for producing graduates with enhanced aptitude for dealing with the challenges of the workplace.

The real-life nature of the project brings a number of challenges, which the authors view as part and parcel of the learning experience. Among the main challenges, the following can be listed:

- Students struggle to stick to the time-line of the project. Study, especially exams, diverts students from project activities. The team lags behind and often has little time to test and tune the race-car before the competition. To minimize any negative consequences, the academic coordinator provides support by helping the students to assess priorities and reschedule tasks. Another means of staying on track is engaging first and second-year students to share the workload. To facilitate students' learning, extensive teaching materials have been developed and made available to students online through unit-specific Blackboard sites. This is in accordance with recommendations of the national engineering association's (Engineers Australia) recommendation to reduce contact hours and encourage self-paced learning [7].
- Sponsor engagement. Complete development of a new Formula SAE racecar requires a budget of at least AU$30,000. Most teams struggle to raise such funds. This compromises the quality and performance of the racecar. This problem is especially acute at universities in smaller cities where potential sponsors may be scarce. Some universities provide substantial funding to the project and try to capitalize on promotion of the project for the purpose of student recruitment. Shortage of funding imposes significant limitations on the quality and amount of components and materials, as well as special literature and periodical publications, that can be purchased.
- In the past, shortage of laboratory space made it difficult to sustain the QUT Motorsport workshop, which is used both for constructing the race car and for teaching. To address the problem, in 2011, the flexible laboratory arrangement was introduced at the BEE Faculty. Much of the teaching hardware is stored outside of laboratories in either on-campus and off-campus facilities. Specific items are brought into the lab when needed. As such the laboratories are highly reconfigurable and all demonstration equipment is mounted on trolleys. This solves the problem of space to some degree but increases the workload on technicians. It is also the case that warehouse storage conditions are not as good as in laboratories and as a result, equipment has an increased risk of suffering damage.

3. Analysis of students' feedback and validation of teaching approaches used

In order to evaluate the efficacy of student learning in the Motor-racing Vehicle Design unit, the following research approaches have been used [8]: experiment, case study and survey. In addition to statistical analysis of customised surveys, the Learning Experience Questionnaire (LEX) was also used, enabling students to provide feedback, via the web, on the subjects that are relevant to this study.

In teaching and social research a number of research approaches can be used. In this research the authors focus on experiments, surveys, artifacts analysis and case studies as research approaches [8]. The experiment in validating new approaches to teaching motor-racing vehicle design is a part of a larger experiment conducted at QUT on validating new approaches to teaching design-related units. In conducting educational experiments researchers focus on contemporary issues and pursue answers to “how?” and “why?” types of question [8]. For example, “How best to teach engineering graphics?” As a research approach, experiment enables control over behavioral events. The survey pursues answers to questions, such as “who, what, where, how many, how much?” Both the case study and survey focus on contemporary issues (e.g. best practices) but do not allow control over behavioral events. Essential components of any case study include [8]: study questions; study propositions (what is the subject of exploration?); units of analysis (students enrolled in particular courses); linking data to propositions (pattern matching); approaches for interpreting studies’ findings (e.g. statistical methods).

Different methods can be used to validate results of a case study, for example: surveys, statistical analysis, interview, analysis of documents (students’ assignments and project reports). An important question that researchers face is whether to make the case study anonymous or not. The authors used anonymous case studies, supporting surveys and interviews because people being interviewed or surveyed anonymously are more relaxed and cooperative.

3.1 Analysis of survey results

A survey questionnaire was distributed among the students that are enrolled in the Motor-racing vehicle design unit. Out of 18 responses the statistical results of this survey are as follows. 16.7% students did not have prior experience in motor racing before taking ENB315 unit, 50% had experience at a very introductory level, and 33.3% had substantial experience in motor racing. Out of all students enrolled in ENB315 unit, 72% are domestic and 28% are international. Out of all students enrolled in ENB315 unit, 50% chose not to participate in the F-SAE competition, 11% participated overseas, 5.5% participated studying at another university, and 33.5% participated studying at QUT. 16.7% strongly agree that participation in F-SAE competition is important for studying the ENB315 unit, 12% agree, 50% are not sure, and 11.1% do not think so. After completion of the ENB315 unit 38.9% students strongly agree that they acquired sufficient knowledge in motor racing vehicle design, 44.4% agree, 11.1% are not sure, and 5.6% do not think so. After taking ENB315 unit 27.8% of students strongly agree that they are adequately equipped to participate in a motor-racing vehicle design, 50% agree, 22.2% are not sure, and none answered **No**. 61.1% students strongly agree that motor-racing vehicle design should be taught as a standalone unit rather than as a part of another design unit, 34.3% agree. 72.2% students strongly agree and agree that completion of the Motor racing major and ENB315 unit enhances their prospects of finding employment in automotive industry, although 27.8% are not sure.

There were also open-ended questions. Typical answers to the question “What did you like most about Motor racing vehicle design unit?” were as follows. “Practical use of the theoretical knowledge”, “Relevance to current motorsport”, “Very interesting with many pracs to reinforce learning.”, “Practical experience every week was very insightful”, “Very informative, covered a wide array of topics”. The question “How would you think we could further enhance the hands-on and practical focus in the motor racing major?” attracted the following answers: “Organize a site visit to a racing team or production facility”; “Introduce a full degree in motor-racing rather than a major”, “Include a practical on assembly/disassembly of a race vehicle”, “Spend a day at a racing track, change suspension setting to see how this affects the lap time”, break ENB315 unit into several units to study in-depth”, “More engine stuff, for example, dyno tuning”.

3.2 Analysis of Learning Experience survey results (LEX)

At the end of each semester, QUT students are encouraged to provide their online responses on their learning experience in different units. Using a five-point system, students provide their responses to questions and also comment on what they liked most and what could be improved. For units related to maintenance and tribology, students ranking of different aspects of teaching from year to year range from 4.5 to 4.8 out of 5, which reflects a high level of student satisfaction. Some students’ comments are quoted as follows: “The highly applicable material, use of real-life examples and high relevance of materials to other units taught during the same semester make this unit very interesting”. Analysis of survey and LEX results show that students overwhelmingly appreciate the hands-on and practical focus of the subjects.

Among the comments on what can be improved students suggested to prepare animations and more hands-on exercises and experiments in laboratory, as well as to have industry visits to motor racing teams' workshops. Some students again suggested to introduce a bachelor of engineering degree in motor-racing rather than just a specialization. These student suggestions are used for continuous improvement of both the content and teaching approach.

4. Conclusions

1. In this paper an important issue of teaching motor-racing through real-life projects is discussed.
2. New approaches to teaching have been presented with emphasis on a practical, hands-on focus. These approaches include:
   - Team teaching: engaging academics with specialist background and experience in engineering design, motor-racing vehicle design, machine condition monitoring, machinery failure analysis and tribology, and technicians with specific motor-racing experience.
   - The use of interactive software packages such as MoTec and Solidworks.
   - Industry visits to motor racing workshops and meetings with motor racing teams.
   - Real-life final year projects, such as projects related to the current race car design and feasibility studies to explore new concepts to be implemented in the future.
3. To evaluate students satisfaction with new teaching approaches, the following methods were used:
   - Special sets of questionnaires for students that are completing the ENB315 unit. These questionnaires also included open-ended questions on what students like most in this unit, and what they think can be improved.
   - Online learning experience survey (LEX).
4. Questionnaires and surveys showed the following:
   - The motor racing specialization (major) is popular among both the domestic and visiting international students.
   - Students overwhelmingly support the hands-on and practical focus in teaching.
   - Students' experience in motor racing varied from "zero" to "extensive" prior to taking the ENB315 unit.
   - Most students believe that they are given sufficient knowledge to participate in motor racing vehicle design.
   - Most students believe that studying the motor-racing engineering second major enhances their prospects of finding employment in automotive or motor racing industry.
5. The feedback obtained in this research validates the new approaches developed for teaching motor racing vehicle design.

References

1. Karri, V., Bullen, F. and Rossmanek, P. "Design and construction of formula SAE race car as project based learning", *Proceedings of the 12th Annual Conference of the Australasian Association of Engineering Education*, 2001, pp. 427-432.
2. Dyn, C.L. and Little, P. *Engineering Design: A Project-based Introduction*, John Wiley & Sons, Inc., 2004.
3. Dyn, C.L. E4 *(Engineering projects) Hand Book*, Department of Engineering, Harvey Mudd College, Claremont, CA., 1993.
4. *2011 Formula SAE rules,* Society of Automotive Engineers Australasia: www. Saea.com.au
5. Tempelman, G, *A stiff challenge*, Race Tech International, October 2009, No. 108.
6. Candy, P.C. *Knowledge navigators and lifelong learners: producing graduates for the information society.* Higher Education Research and Development, Vol. 17, No. 3, 2000, pp. 261-277.
7. Accreditation Management System for Professional Engineers, *Engineers Australia*, 2010. http://www.engineersaustralia.org.au/about-us/program-accreditation/management-system-for-professional-engineers/management-system-for-professional-engineers_home.cfm
8. Yin, R. *Case Study Research, Design and Methods*, Applied Social Research Methods Series, V5, SAGE Publications, 2003.