PROMOTING INTERDISCIPLINARY LEARNING IN A PRACTICAL ENVIRONMENT USING THE FORMULA SAE COMPETITION

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Abstract

Interdisciplinary learning flourishes in situations where students are self motivated to draw on a broad range of knowledge in order to solve a challenging Engineering problem. A key element in this picture is the need for a high degree of self motivation i.e. enthusiasm and excitement coming from the students (not the teacher) for the project. The Formula SAE project, developed and run for more than 20 years by the Society of Automotive Engineers (SAE) in the USA provides an excellent example of this in operation. For many students a brush with real motor sport and the opportunity to push their Engineering skills to the limit is all they need to bring out the best in integrating and extending their knowledge base. This paper reflects on involvement in this project at the University of Wollongong over recent years, the ways the competition contributes to the education of the students who are engaged in it, and the extent to which it has facilitated interdisciplinary activity in the faculty.

The Engineering Education Challenge

The field of Engineering contains a vast and growing body of knowledge and imparting sufficient of this to students in order to constitute a satisfactory undergraduate program presents many challenges to educators. One challenge is to identify a suitable selection of this knowledge to focus on in the course. Often one of the thorniest debates when reviewing an Engineering curriculum is to decide what to leave out. Compelling cases can be made for the fundamental importance of almost every field of study. Most educators will have a field of expertise, and they will take a particular responsibility to present this material to the students in their institution (and arguing for its inclusion in the program) in addition, no doubt, to contributing to the common core foundation subjects.

Another challenge is to develop teaching strategies and structures to efficiently deliver the selected set of knowledge to the students. Typically, this means identifying subject streams running through the program, for example: fundamental sciences (physics, chemistry); mathematics; statics and dynamics; materials; fluid mechanics; thermodynamics; design; control; manufacturing and management.

Material in each of these streams can then be condensed into specific subjects that lead students in a logical and related manner to a deeper understanding and competence in each of these fields. This is necessary to assist students in gaining a clear picture of related theory and the subsequent application of that theory for each of the topic areas.

It is also necessary to compartmentalise material in this way in order to provide an efficient framework for the delivery of this knowledge. Institutions do not have the luxury of an unlimited time frame for the delivery of their courses. Four years is the standard time frame expected for an undergraduate Engineering degree, and an institution expanding beyond this time period would find itself at a disadvantage when students weighed up the comparative merits of competing universities.

Beyond the effective transmission of the theory and practice of the knowledge base relevant for a particular Engineering discipline, is the need to place that discipline in context with other disciplines, both within and outside the traditional Engineering fields. Usually this is addressed in a general way in the early stages of the course by way of introductory subjects and possibly before the students have chosen a major for their degree. Later on in programs the pressure of delivering the desired content and depth limit the space for more interdisciplinary focus.

The Challenge for Students

The current structure of engineering courses assists students in building up their competence by allowing them to focus on a rational sequence of topic areas. The program will have a framework of thoughtfully sequenced subjects (generally resulting in a fairly rigid timetable that can cause some problems for students and institutions) that build the knowledge steadily from semester to semester. Generally this means that within each subject students develop an expectation that the problems posed can generally be met by reference to the text, subject notes and worked solutions that have been provided within that subject.

In other words, the reality of open-ended real world Engineering problems has been transformed into a subset of problems that can be addressed by the principles and techniques of the subject currently being studied. The educators involved will be aware of the big picture context of the material they are presenting and often of alternative principles that could be used in the same problem (possibly even superior in that application). However, their primary responsibility at that point in the course is to ensure that the students gain a solid grounding in the specific subject content that they are presenting.

Hence an unintended consequence of this structured approach to the presentation of the material is the development of a compartmentalised internal knowledge structure within the students themselves. There is a strong expectation from students that when a problem is posed within a subject, the solution strategies, the relevant theory and formulae, will be close at hand – within that subject text and/or notes.

The goal, of course, is for students to move towards a more mature understanding of their Engineering discipline by integrating the knowledge from the full range of subjects studied over their course into a cohesive whole. For those who persist in their profession, this will occur, but possibly not reach a reasonable level until their understanding has been refined through some years of professional practice.

Some subjects more specifically seek to foster this kind of integration of knowledge – for example the final year projects and capstone design type subjects. Typically these will not be of an interdisciplinary nature, and indeed the coverage of their own discipline will be variable depending on the topic being addressed. Often it is difficult to develop these problems without a pre-determined solution already being available in order for the educator to be confident that a satisfactory outcome is possible.

The Challenge for Institutions

The institution (Engineering Faculty or School) faces both these challenge areas. Within the current competitive educational marketplace it needs to contain costs by presenting its courses in an efficient manner. It needs to remain within the norms for these programs when compared with the alternative courses being offered to students. However, it is also critical that the standard and reputation of its graduates reflect very positively on the reputation of the program being offered – so there are really no short cuts available that will work in the medium to longer term.

Problem Based Learning

An attractive educational option, in terms of fostering an integration of knowledge both within and across disciplines, is to challenge students with a fairly open ended problem to solve. Within the framework of this problem, students can be encouraged to draw on all areas of their course in order to develop feasible solutions and hence achieve an integration that is need driven and hence validates the concept directly for the students.

Unfortunately this is not necessarily a work saver for the academics involved. It is not easy to develop appropriate problems that have the capacity to draw in large areas of the course – let alone other disciplines. It is necessary to continually renew the problems set, as the database of past solutions undermines the freshness of the challenge that is intended to be set before the students, and hence undermines the internal integration of knowledge that could be gained. It is also difficult to pose these kinds of learning experiences within the tight time framework of the existing course structures. Ideally, the academics involved would need to solve the problem themselves to ensure it has the potential to fit within some required time period. Coupled with the need for constant renewal, this can very difficult to maintain when set against the other demands on contemporary academic life.

Ideally what would be required is a self-renewing project that requires the application of a broad range of knowledge and skills from across the disciplines. Ideally the project itself would enthuse and inspire the students to achieve to their highest possible level. They need to be committed to the outcome, and consequently are essentially self assessing their work to a large extent. It should allow for innovation, but also require the rigorous application of theory and analysis in evaluating and optimising the solutions being developed. The development of a physical product would be a major bonus, extending the paper calculations and output of the majority of the Engineering educational experience. The incorporation of teamwork, leadership and project management into the exercise would assist in broadening the educational experience and provide a very valuable preparation for work as engineers after graduation.

The Formula SAE Project (F SAE)

The F SAE project is a collegiate competition developed and run by the Society of Automotive Engineers (USA) for more than 20 years, as one of a number of collegiate competitions designed to foster Engineering in a range of disciplines. It is interesting to note that its initial motivation was probably from the other end of the Engineering education train, i.e. it was and is driven by the desire of employers to promote study by good students in fields that are of relevance to their commercial activity, and to then have access to those students as they graduate. The continuing support (and indeed expansion) of this competition can hence provide some confidence that the outcomes in terms of the capabilities of the Engineering graduates involved are very beneficial.

The project is posed in the following context:
Student teams are to develop a design for an open-wheeler race car that would be suitable for a person involved in weekend autocross events (a type of amateur motor sport often held in large car parks in the USA, that involve vehicles negotiating a tight track on a time trial type basis). A number of constraints are imposed on the vehicle – for example, the total construction cost must be under A$50,000. Engines are limited to 610 cc capacity, and must be 4-stroke configurations. Extensive regulations relating to the safety of the vehicle have been developed and occupy the majority of a ninety plus page rules document. This includes structural requirements, roll bar locations and sizes, dual braking systems, engine breathing restrictions, throttle and electrical system safeguards, noise limitations etc. Despite the constraints outlined very briefly above (but covered in detail in the rules document) the scope for innovation is very wide and allows very different designs to be developed. The Society of Automotive Engineers – Australasia decided to bring this competition to Australia in 2000, and have subsequently conducted five competitions (F SAE-A) since that time.

Student teams have one year to complete the project, from design to a finished vehicle.

The Evaluation

The student's work is evaluated in a series of static and dynamic events judged by panels of industry experts at an annual competition [1]. The static events involve cost, sales and design presentations and require high standards of communication skills, in addition to a sound grasp of the technical and financial/management strategies of the team.

The dynamic events are a stern test of the technical merits of the design developed by the students. These events (Acceleration, Skid Pan, Autocross, Endurance and Fuel Economy) are designed to explore the performance limits of the vehicle in a realistic and demanding context. Multiple drivers are required to complete the dynamics events, hence good ergonomics are important for an effective design. More subtly, a good performance at the annual event is heavily dependent on the effectiveness of the teamwork and project management skills developed by the students. Sufficient time for testing the vehicle prior to the competition, making any necessary changes and providing for driver familiarisation/training, is of vital importance if the team is to perform to its potential.

Formula SAE Project Content

There are a large number of excellent features of the F SAE competition in providing a successful framework for problem based learning that fosters the integration of knowledge both within and across Engineering disciplines (and beyond).

Most importantly the concept of the project excites and motivates the students who choose to become involved. For many students, particularly (but not only) those of a Mechanical Engineering persuasion this project epitomises the attraction of Engineering for them in the first place. Hence student motivation is not a problem. They are drawn into the project and, as recorded by Moreno et al [2], need no encouragement to push the boundaries of their knowledge in order to develop a solution that satisfies them, not some external examiner. The work is consequently self-assessed at several levels. Firstly, the students are usually their own hardest markers, as they want the outcome to meet their own high standards for the design. Secondly the competition itself, in particular the dynamic component, is an objective measure of the Engineering merits of their design.

Secondly the technical scope of this project is extremely broad. Virtually every technical aspect of a standard Mechanical Engineering course contributes critical elements to the design. Examples include: design and stress analysis in the chassis; mechanism analysis in the critical suspension and vehicle dynamics areas; heat transfer in the engine cooling and braking systems; combustion engineering and thermodynamics in the engine set up and modification; fluid dynamics in the design of intake and exhaust systems – and potentially in the development of aerodynamics packages for the car; manufacturing principles and alternatives in the manufacturing of the wide range of components required; work with composite materials and adhesives in developing bodywork components and so on. In addition, the students need to substantially extend the necessarily limited exposure they have had in other aspects of the course in order to meet the demands of this project. For example the one year time frame of the project makes 3-D computer modelling and assembly of virtually all components of the car prior to commitment to final design and manufacture an essential stage for the project. The interdisciplinary nature of the project is highlighted in the technical area by the increased reliance on electronics and control in modern motor vehicles. In this case, to obtain competitive performance from the engine package, it is necessary to concert the engines from carburettor to fuel injection systems. This entails the incorporation of engine management systems to monitor and control injection and ignition timing and injection duration over the range of engine load states. There is also the need to read in sensor data (throttle position, engine RPM, manifold pressure and exhaust oxygen content) to enable the correct operation of the engine package. Opportunities exist to extend this technology into areas such as the installation and control of turbochargers, wheel speed sensors for traction control, suspension displacement data logging and car to pit telemetry. Of course, there is also the need for all cars to design and install the wiring loom, including the mandatory electrical safety circuits.

The dynamic, interdependent and challenging nature of the tasks undertaken by the students certainly promotes the kind of active learning suggested by Huang [3] as one of the curriculum reform goals for contemporary Chinese education. Involvement in the project is seen as a key feature in illustrating and implementing desirable educational outcomes by many schools as indicated by [4], [5] and [6].

Communication, report writing and presentation skills also get a very heavy and realistic workout in this project.

The nature of this project reinforces the interdependence of all these technical elements in the design of a successful vehicle. The need to exercise Engineering judgment at many stages in order to come up with what the team considers being the best compromise of cost, function and performance relies on an acceptance of the interdisciplinary dependence of many of the systems, and an effective integration of the technologies to make a working whole.

The third element of note is that this project is in effect a major project management task in disguise. The lure of building a high performance race car generates the motivation in the students and inspires them to levels of excellence and effort rarely seen in other parts of the course. However, to successfully achieve the goal of producing a real vehicle within the tight time frame requires a determined focus on teamwork, leadership skills, communication, budgeting, dealing with sponsors, dealing with suppliers, setting milestones and monitoring the performance of the team in relation to those milestones. Reacting to organisational difficulties and dealing with crises are another feature of the challenging road of bringing this project to fruition. From our experience with this project over the past 4 years it would seem reasonable to conclude that effective project management is at least 50% of the challenge that the students face in bringing it to a successful conclusion. These skills are dealt with to some extent in the standard Engineering course; however, it tends to be a difficult area in which to raise student interest. Placing the concepts within the framework of a real project that the students are committed to and responsible for completely changes their appreciation for this material, and hence raises interest level and learning outcomes. The focus on teamwork, commercial skills of budgeting and cost monitoring and control and maintaining an effective organisational structure through the project (including, for well performing teams, planning for the future – not just the current year's competition) is another example of extending the discipline boundaries for the students.

The University of Wollongong F SAE Experience

The University of Wollongong was not directly involved in the first competition organised in Australia. However, a group of students was aware of the competition (some had attended US Universities on Study Abroad arrangements and had seen the competition on its "home ground") and made the effort to attend the inaugural event with one of the authors. The team entered for the following year and immediately moved to set up team structures that would provide a stable framework for the completion of the project. There has been some variation in the structure over the subsequent 4 years, but essentially the structure consists of a Team Leader for the overall project, with a number of groups being established for identifiable sections of the task: Chassis and Body; Suspension; Engine; Drive Train; Electrical and Project. Each of these groups has a group leader and group members are distributed around on the basis of interest and need. The Team Leader is responsible for keeping the big picture in mind and making the major judgement calls when necessary, supported by meeting with the group leaders. The group leaders hold regular meetings within their sections to ensure regular progress on the design and manufacture of the components they are responsible for. Group leader meetings and Team meetings are held regularly to maintain the integrity of the design, identifying and resolving design conflicts that may arise between different areas as well as progressing general management issues.

Team members are drawn from all years of the course, from first year to postgraduate level. This spread of years is vital for building and maintaining a "corporate memory" for the team, reducing the opportunity for mistakes to be revisited. For the students it allows a maturing of their understanding of teamwork and leadership in a challenging Engineering project as they progress from a novice phase to increasing levels of responsibility and leadership. The mentoring involved not only boosts the teamwork skills, it also strengthens technical understanding of complex Engineering issues and is of great value to both the novice team member and the mentor who is refining and clarifying his/her own knowledge in the process of passing it on.

As has been noted earlier, project management, teamwork and leadership skills emerge as major factors in the course of this project. To an extent not experienced elsewhere in the course the students are faced with the direct need to master the challenges of this element of engineering if they are to realise their goals. Hence it is a very rewarding area to explore management options and styles, and observe the outcomes (which come in sometimes disconcerting degrees of reality). A perennial top performer in the US F SAE competition, Cornell University, clearly place a big emphasis on this element of their programs and have developed interesting options, as indicated in their discussion on subteam reformulation [7]. Variation in team structures mirrors the variety of technical solutions adopted by different teams, with arrangements ranging from minimalist adhoc "backyard" groupings, university sporting clubs (with constitutions) to the corporate style structures with a board of directors and technical and management divisions as described by [2]. One of the major challenges identified for the University of Wollongong in sustaining an effective involvement with this competition is seen to be the development of improved teamwork and project management skills. This is both in the areas of provision of enhanced management skills and support materials for the students, and in strengthening the appreciation of students – at earlier levels in their study – of the value of gaining experience in this area.

The interdisciplinary nature of the project is demonstrated by the range of disciplines represented in the student team members. Mechanical and Mechatronic Engineering students are the major grouping. However, Electrical Engineering has always been solidly represented. Materials Engineering, Computer Science, Computer Engineering, Commerce and Commerce/Law students have also been vital members of the team. The extent of this interdisciplinary mix is well illustrated by the Team Leaders who have led the team to date. In 2001 the Team was led by Derek Powell (BE Mechanical), in 2002 by Justin Ulland (BE Mechanical / BA English Lit), in 2003 by Fergus Wilson (B Commerce / B Law), in 2004 by Michael Schilling (BE Electrical) and in 2005 is being led by Bryan Maris (BE Mechatronics). The experience for these students in leading a multi-disciplinary team in a complex Engineering project is invaluable. The range of disciplines that the Team Leaders have been drawn from clearly illustrates the recognition within the team of the interdisciplinary skills that are essential in bringing the project to a successful conclusion.

Providing appropriate academic credit for the work undertaken by the students is an issue of some concern in relation to this project. The educational value of the experience is very clear to students and staff who have been involved, however most of the activity is extra-curricula, and hence on top of the already demanding academic load for the students. The major avenue for students to receive academic credit has been via the final year thesis / project – typical a 12 credit point unit which amounts to approximately 6% of the overall course credit. Approximately 30 theses have been completed in association with this project to date. In addition a number of 6 credit point projects have been supervised, effectively half-scale theses, allowing some students to gain up to 10% of their overall course credit in the course of the work on the team. In recent discussions with a number of US universities who have had long involvement with the project this extent of integration of the project into the academic load appeared to be above the norm (around 3 to 4% was typical)

Results and Outcomes

One virtue of this competition is the opportunity it provides for the students to test their skills against their contemporaries from other universities on both a national and international stage. It is fair to say that on this level the performance of the University of Wollongong Team (which is no doubt built to a significant degree on the structures adopted, and the manner in which the team has embraced the interdisciplinary opportunities offered by the competition) has been remarkable. The UoW Team won the first F SAE – a competition it entered in 2001 (and was narrowly beaten by a visiting US team from the Rochester Institute of Technology – a team with many years of successful experience in the competition – in the international component of the competition). In May 2002 the team attended the international competition and finished in 28th place after a problem in the Endurance Event saw them fail to finish in that event). Nevertheless, the team placed second in the Design Event. In December 2002 the UoW team eclipsed the previous record F SAE point score record in taking out the F SAE-A event, in the process winning all the dynamic events (a feat that has not been equalled either before or since). In May 2003 that vehicle was taken to the international competition in Detroit where it again took out first place – the only team from outside the USA (there has a corresponding European competition for a number of years, and international teams coming from Japan and South America) to ever take out the event. In December 2003 the UoW Team placed a creditable 6th after grappling with an engine overheating problem. This car was again taken to the Detroit competition in May 2004, where it finished 11th out of 140 teams. This was the top position of any of the non USA teams competing. In December 2004 the fourth car produced by the team again finished first in the F SAE-A event, coming in ahead of highly credentialed international teams, but actually facing stiffer competition from extremely competent Australian (and one New Zealand) teams.

Photo 1 shows the 4 cars built by UoW Racing and the location of the 7 events in which they have competed.

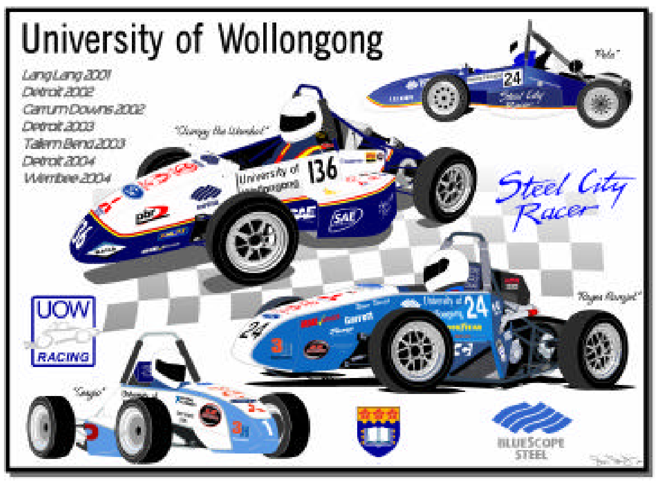

Photo 1 – The 4 F SAE Cars Built by UoW Racing

This excellent record of performance in a very challenging competition has gained the University of Wollongong a high profile in this event internationally. It has allowed the students involved to demonstrate the comparative strength of their degrees (a significant number of students have been able to follow their dreams of working in motor sport as a result of their involvement with this successful activity). Their involvement has made them attractive to prospective employers in and out of the automotive arena.

This performance has not been built on a flourishing automotive stream within the University – no such specialisation is offered, though experience with the project has provided the incentive to strengthen aspects of the course in this area. It is anticipated that it has come from a solid foundation in Engineering principles and design, effective project management and teamwork, good support from the University (facilities, funding and staff) and local sponsors, effective embracing of interdisciplinary skills by the Team. The most significant element, however, has most likely been the enthusiasm and dedication of the students involved, particularly in the initial years of involvement who established a standard of achievement for subsequent teams to strive for. The ongoing challenge for the University is to find ways to enhance the educational value of the project for the students (perhaps by more effective and flexible integration of the activity within the academic program – with possibly a focus on the management stream of the course), and at the same time maintaining an appropriate level of support (staff, facilities and funding) to ensure that the students have a solid foundation to build from.

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