EXPERIENCE WITH PBL SHARED ACROSS MULTIPLE COURSES

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ABSTRACT

The Micro Aerial Vehicle Design Build and Fly (MAVDBF) Challenge was introduced in 2010 as a motivational and unifying learning platform for students in the second year of the aerospace engineering program at the Royal Melbourne Institute of Technology (RMIT). The project was conducted across three courses being delivered in the second year of the program in order to help students integrate learning in design, systems engineering and aerodynamics. This paper describes experience of the MAVDBF Challenge during 2010 and 2011.

The project was associated more strongly with the systems engineering course rather than the design course for reasons that were primarily practical rather than philosophical. In addition to enabling integration of learning across distinctly different but relatable sub-discipline areas, assessment of the varied elements within the MAVDBF Challenge entailed allocation of marks equivalent to 60% of the total assessment for a standard 12 credit point course. The allocation of assessment for the project was 25% of total assessment for Systems Engineering (Preliminary design, Validation, Peer assessment), 25% of total assessment for Aerodynamics (Aerodynamics analysis and design report), 10% of total assessment for Design (development of model in CATIA). This quantum of marks provided enough encouragement for students to dedicate an appropriate amount of time to the project – commensurate with the allocation of marks it was anticipated that reasonable project outcomes could be achieved by students working in teams of five with each student contributing a total of 30-45 hours to the project, which represents about 60% of the total non-contact student hours for a standard 12 credit point course. It is worth pointing out that the majority of marks for each of the three contributing courses were allocated to conventional assignments, tests, and examinations, which subsequently proved to be a source of student dissatisfaction.

The MAVDBF Challenge was the first such multi-course project conducted by the School of Aerospace Mechanical and Manufacturing Engineering at RMIT, and it was intended to demonstrate an alternative educational approach that could be employed in other courses.

The project was successful in creating motivation for both students and staff, and enabling deeper learning of content through application and integration. Research in the following year in relation to a new incarnation of the Challenge showed that whilst student motivation and enjoyment were again at high levels and student opinion expressed a preference for this kind of activity, there was a sense that the assessment reward was not in proportion to the effort required.

KEYWORDS

Design, Project Based Learning, Aerodynamics, Systems engineering, MAV

INTRODUCTION

The Royal Melbourne Institute of Technology (RMIT) has provided education with a focus on application since 1887. RMIT has delivered aerospace-relevant education at a range of levels since 1937. Organisationally located within the School of Aerospace Mechanical and Manufacturing Engineering, Aerospace engineering staff work closely with industry partners and a range of research collaborators.

The Aerospace engineering program attracts typically about 80 students each year, of whom one third are from overseas. Students admitted to Aerospace engineering from high school are generally in the top 10% of school leavers.

Since its inception, the four-year Aerospace engineering degree program has consistently maintained an emphasis on aircraft design. In the current program structure, 15% of the courses are dedicated to aircraft design with additional courses contributing to design awareness in tandem with development of analytical skills. Despite this substantial commitment to design, a number of academics felt the program could be improved by introducing approaches that would better assist students in developing a more coherent understanding of how parts of the curriculum related to each other, and also more experience in synthesising these parts into satisfying design outcomes.

The Micro Aerial Vehicle Design Build and Fly (MAVDBF) Challenge was introduced as a motivational and unifying learning platform for students in the second year of the aerospace engineering program. The project was conducted across three courses in the second semester of the second year in order to help students integrate learning in design, systems engineering and aerodynamics. This stage of the program was selected as it is the first semester in which the aerospace curriculum has branched away fully from that of other engineering programs in the School, such as mechanical, manufacturing and mechatronics.

At this stage, in the fourth semester of the program, there are three concurrent courses with a clear focus on “the aircraft”: Systems Engineering, Introduction to Aerodynamics, and Aerospace Design 2. In preceding semesters, students have undertaken courses that introduce aircraft nomenclature, principles of flight, aircraft design concepts and other relevant themes, but these are introduced in a sequence to help students absorb key concepts rather than being studied together. It was believed that by the fourth semester of the program students have learned sufficient key concepts are ready to integrate their learning through more challenging and integrative experiential activities.

The project was primarily coordinated from the systems engineering course rather than the design course for reasons that were primarily practical, relating to individual course learning outcomes and topic sequencing.

The use of projects in engineering programs, even in second year, is not a new idea. The University of Aalborg adopted a curriculum-wide, project-based approach as early as 1975 [1]. Prince and Felder have discussed the benefits of inductive learning approaches, such as PBL [2]. The CDIO community provides many examples of project-based learning and it provides excellent support for newcomers to the field [3].

Integration of separate courses through a common project is, however, quite challenging, as we will discuss. Crawley et al [4] discuss the use of projects that run across two or more courses and there are some recent examples [5, 6].

THE MAVDBF CHALLENGE

In the 2010 MAVDBF Challenge, students were required to conceptualise, analyse, design construct a solution in the form of a remotely-piloted micro aerial vehicle, and then demonstrate its operational effectiveness against a complex set of performance criteria.

Students faced a scenario where an aircraft carrying five aid workers was reported missing as it flew to a United Nations camp located at a remote airfield a short distance away from an active conflict zone. The aircraft needed to be located, and the location and identity of any survivors was to be determined to enable a subsequent rescue mission to be mounted. It was suggested that survivors may have fled the downed aircraft to evade capture and could be some distance away from the aircraft in any direction. Survivors could be individually identified by the colour of their clothing.

The search area itself would not be visible during flight operations, but the aircraft flying above the search area would be visible. Video information required to locate the downed aircraft and survivors would be acquired and recorded by a small digital video camera mounted onboard each Micro Aerial Vehicle (MAV).

For the purpose of this project, the search area and airfield were situated within an indoor standard-size netball (basketball) court with relevant zones indicated in figure 1 below. Survivors were represented by toy bears with uniquely coloured vests, and the downed aircraft was represented by a model aircraft of appropriate type. To simplify location of survivors, the search area was prepared with a grid overlay as shown in figure 3 below. Student groups flew their “mission” in turn; each group having two turns. Students were unable to directly observe the locations of any objective target (bear or aircraft model), and the locations of these were altered for each MAV flight. An example flight path is given in figure 2.

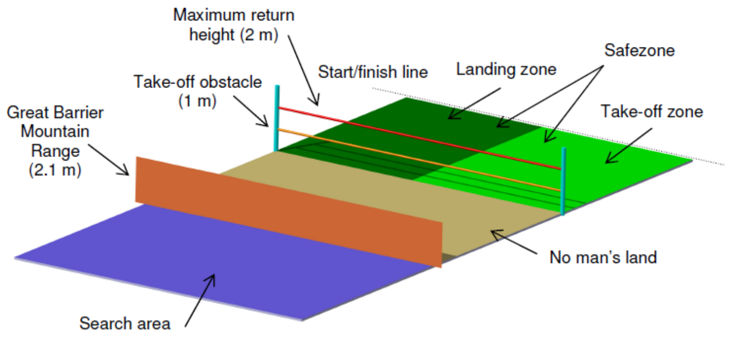

Figure 1. Schematic diagram of flight operations area

The mission had a number of specific requirements:

1. The MAV must initiate take-off from the “start/finish line” in the “safezone”, and clear an obstacle one metre above the ground at a distance 10.2 metres from the start/finish line.
2. The MAV must fly over “No man’s land” and clear the “Great Barrier Mountain Range” (2.1 metres high) to enter the “Search area”
3. Once above the search area the MAV should fly a search pattern that will allow the location of all survivors and the downed aircraft to be recorded discernibly by the on-board video device.
4. After completion of the search phase of the mission the MAV must return to the safezone by flying over no man’s land.
5. To avoid detection and possible destruction during the return to safety phase (by hostile forces that could be in the area), the MAV was to enter the safezone at a height no more than two metres and glide towards the start/finish line with power off.
6. After landing the on-board video device was to be retrieved and video footage downloaded and viewed in order to identify location of mission targets.

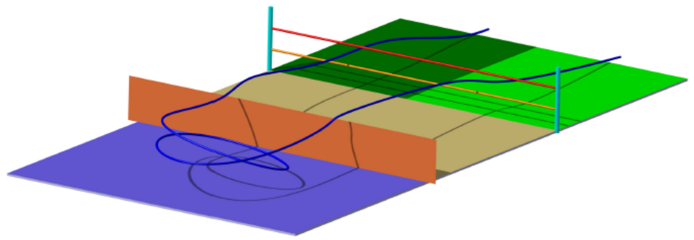

Figure 2. Example of a mission flight path

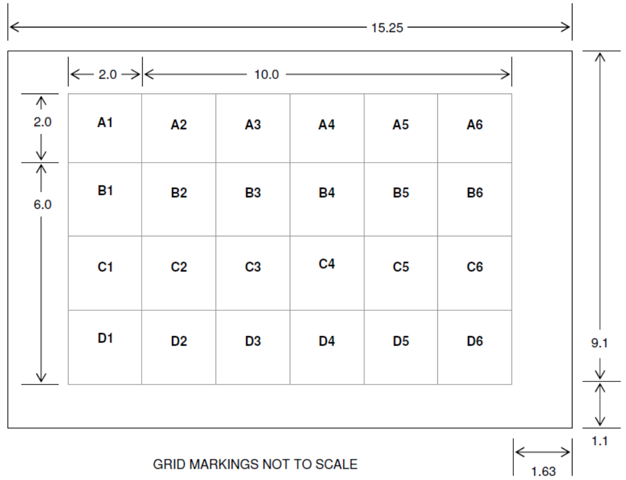

Figure 3. Grid overlay for search area (dimensions in metres)

The scoring system used for MAV performance in the mission was deliberately complex to encourage deep thinking during the design conceptualisation and also to provide reward for optimisation of diverse requirements. The total score awarded was the sum of points for “Size”, “Time”, and “Mission”.

1. Points for Size, $S = \frac{(800 - s)}{10}$ where s is the wingspan in mm
2. Points for Time, $T = (120 - t)$ where t is the flight time in seconds, however Time points could be awarded only to MAVs that flew a “legitimate” search mission and then reached the safezone
3. Mission points, $M = P + G + L + I$ where
   a. P are points awarded for achieving different phases of the mission (for example 18 points for clearing the take-off obstacle height),
   b. G are points awarded according to how close (d mm) to the start/finish line the MAV came to rest after landing, $G = \frac{(10200 - d)}{100}$
   c. L are points awarded for locating each survivor (20 points for each), and
   d. I are points awarded for correctly identifying each survivor (20 points for each)

MULTIPLE COURSE CONTRIBUTIONS TO LEARNING AND ASSESSMENT OF THE MAVDBF CHALLENGE

The 2010 MAVDBF Challenge project was conducted across three courses taught concurrently – Systems Engineering, Introduction to Aerodynamics, and Aerospace Design 2. These courses were complementary but also contained areas in which topics were reinforced by consideration from different perspectives. For example, the aerodynamics course introduced concepts central to flight mechanics and techniques for analysing flight performance, and the design course considered analysis of flight with a view to optimisation. Table 1 indicates the learning outcomes for each of these courses.

Table 1

Learning Outcomes for courses contributing to MAVDBF Challenge

Course	**Systems Engineering**	**Aerospace Design 2**	**Introduction to Aerodynamics**
Course aims	The Systems Engineering course aimed to equip students to analyse a wide range of complex problems and apply Systems Engineering concepts and techniques to Aircraft Systems from an operational perspective	The Aerospace Design course aimed to give the student an appreciation of the processes and methodologies applied to aerospace systems design. Includes application to simulated parts and assemblies and conformance to international standards.	The Aerodynamics course aimed to provide an introduction to concepts and application of theoretical low-speed aerodynamics, and an introduction to high-speed flow.
Course Learning Outcomes	Describe and discuss the elements of the System Life Cycle Apply functional analysis to engineering systems Analyse the strategy used for a complex problem and comment on its effectiveness Devise appropriate solution strategies for complex problems, taking into account the environment and conflicting requirements Apply a systems engineering approach to a problem in the aviation domain, considering operational, design and support perspective, and analysing the functional characteristics of the problem Integrate the principles of systems thinking into analytical thinking skills.	Identify aircraft components and methods for their design and manufacture; Select and analyse aircraft structural components, assemblies and joints; Make initial estimates of aircraft loads; Explain traceability in aircraft design.	Demonstrate understanding of fundamental principles in theoretical and applied aerodynamics, and Demonstrate ability to apply these principles in the analysis of simple, but essential, aerodynamic behaviour relevant to typical practical applications.
Percentage of course assessment related to MAVDBF	25%	10%	25%
Nature of assessment relating to MAVDBF	Assignments based on MAVDBF Challenge systems analysis Preliminary Design Review and Critical Design Review, and validation at “fly-off”. Performance of the actual flown mission was assessed within the System Engineering course	Use of CATIA to create 3D representation of team MAV concept	Prediction of MAV performance based on aerodynamic analysis, and reflection of actual performance at “fly-off” when compared with predicted performance. Submission via a team engineering report.
Course study areas relevant to MAVDBF project	Systems engineering concepts, functional decomposition, requirements definition. Design team roles and teamwork. Conceptual design, preliminary design.	Aircraft design process, graphical communication of components and assemblies using CATIA. Design optimisation.	Aerodynamic concepts and performance analysis for steady level flight, glide, climb, turns, etc.

Milestones (progress gates)

The project contained some milestones that students need to meet in order to gain approval to progress. For example, standard aircraft components (wheels, propeller, Lithium polymer battery and electric motor) and construction materials (Depron foam sheet, glue, materials for pushrods, hinges and control horns) were issued only after the student teams had submitted a detailed CATIA drawing of their MAV concept and gained approval from a tutor or designated academic.

Radio control equipment sets were issued only after a minimum of one team member had passed pilot skills training and certification. Pilot skills training was undertaken on a PC-based flight simulator, which was controlled by a standard-issue radio control unit in which the outputs were communicated to the simulator by electrical cable rather than by radio signal. The simulated aircraft had characteristics that were "typical of class" for the expected student designs. Through this process students could develop a reasonable level of skill in controlling an MAV-type aircraft through all required phases of flight.

Students were required to undertake a safety induction at the start of the semester, and given workshop support in the form of advice for fabricating parts and oversight in the initial fabrication process. Students were issued with a battery charger only after they had demonstrated understanding of the OHS issues and risks, and safe operation of these devices.

Student teams had the opportunity to gain experience test-flying their designs at the netball court two weeks before the actual challenge "fly-off" but the court was open and not fitted with of the barriers or the search area grid that would be present at the fly-off. Some student groups found that redevelopment of their design was required at that stage.

Key design consideration

Early in the project, students generally did not anticipate that the on-board micro video camera system would have a very significant influence on their designs and their strategy for conducting an appropriate flight pattern over the search area. The video system chosen was small and light, which appeared to be well-suited to the task but the system also imposed important system limitations in the form of low resolution, slow frame rate, and modest field of vision. These limitations imposed significant constraints on flight speed and range of pitch and roll angles that the MAV could operate at and still provide the necessary functionality for the search task. It was only when students grasped this that they could properly set about the design activity. In order to obtain information about the video camera performance students needed to set up their own experiment to determine the range of acceptable distances from the grid numbering, speed across the viewing target, and optical acceptance angles.

OUTCOMES: WHAT WAS LEARNED ABOUT HOW TO CONDUCT SUCH PROJECTS?

Staff experience with the MAVDBF Challenge was varied, and in some respects almost contradictory. Consideration of the collected experience generated suggestions for improvement of these types of projects. Whilst student satisfaction with the project was generally very high, one perceived shortcoming from the perspective of staff was the inability within the implementation in 2010 to determine the impact of the project on student learning, and in particular how introduction of the changes to learning and assessment impacted on course learning outcomes.

For the courses that most strongly connected with the MAVDBF Challenge student commentary through the semester and in the institutional surveys conducted at the end of semester was overwhelmingly positive about the activity, with frequent expressions of enjoyment, positive challenge, and enhanced connection between theory and practice. It was interesting that in the institutional course surveys some students made explicit positive comments about connection between courses even though each of these surveys asked for feedback only on a single course.

It was interesting to note that the level of student satisfaction in all three courses was relatively low in 2010 despite the widespread positive comments made by students in the same surveys. Metrics are shown in figure 4 for the Aerodynamics course as an example. This appeared to be a consequence of extraneous factors that affected satisfaction with the courses overall but did not reflect on the minor proportion of the courses that related to the MAVDBF. Examples of this included dissatisfaction with change of lecturer mid-way through the semester (necessary as a response to unforeseen circumstances).

The background context and specific requirements of the Challenge project was altered and somewhat simplified in 2011. The Challenge scenario was to design and build an aircraft to introduce passengers (in the form of M&Ms) to the joys of recreational flight through a commercial service. In this second year, the project required optimisation of performance based on a single measure – maximisation of "M&M-seconds", the product of M&M payload (number of M&Ms carried) multiplied by flight time.

The experience with that version of the MAVDBF was again somewhat contrary to expectation. In 2011 student satisfaction was high in the courses involved with the MAVDBF, but whilst a majority of students commented favourably on the value of the Challenge to their learning, a stronger volume of sentiment was expressed about mismatch between the large amount of work required and the perceived inadequacy of marks allocated to some of the tasks.

Figure 4 shows that mean performance in the final examination at the end of semester was not well-correlated with student satisfaction. While this is not surprising, it was disappointing that the high level of student motivation for the project did not stimulate higher levels of engagement with other aspects of the course leading to improved examination performance. Even higher levels of satisfaction in 2011 did not address a reduction in exam performance. The aerodynamics course was stable and the examination format changed little through the period 2007-2010. In 2011, the exam duration was reduced from 3 hours to 2 hours to comply with university requirements, and despite the consequent adjustment to the examination difficulty and length it is unreliable to directly compare mean exam performance with that of earlier years. In addition, it is difficult to determine whether or not there was any impact on students in this study arising from their experience in undertaking a complex design task as part of the Engineers Without Borders (EWB) Challenge in the preceding year. Students engaged in the MAVDBF project in 2011 had experienced the EWB Challenge, but their predecessors had not. It is possible that prior experience with more open-ended projects may have contributed to increased levels of course satisfaction.

Figures 5 and 6 show the individual student performance in the examination for the aerodynamics course and in the MAVDBF assessment for the same course, respectively in 2010 and 2011. The particularly low correlation in 2010 between these two measures of student performance (R^2=0.0296) is believed to be due to two factors:

1. the examination was an assessment of a broad range of cognitive skills, many of which differed from those being developed and assessed in the MAVDBF assignment within this course,

2. the assessment connected with the MAVDBF aerodynamics covered a very broad range of primarily analytical tasks that were not strongly interconnected. These decoupled tasks enabled students to operate relatively independently so that they could opt to not work together and thereby forego opportunities to share learning of technical skills and improve their team skills.

For the implementation in 2011 the learning outcomes for the "MAV assignment" were altered. In comparison with the previous year, the emphasis on this assignment was on more subtle consideration of a reduced number of elements. In 2011 the activities were more interrelated and students needed to work in teams to determine meaningful solutions. The coefficient of correlation between student assignment and exam results increased to R^2=0.1266 in 2011.

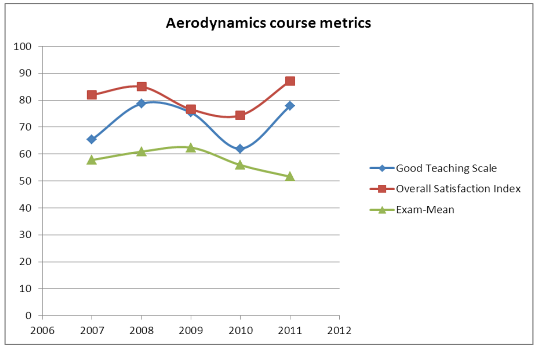

Figure 4. Variation by year of student perception of teaching quality and overall satisfaction, and class-average exam performance. The MAVDBF project was introduced in 2010.

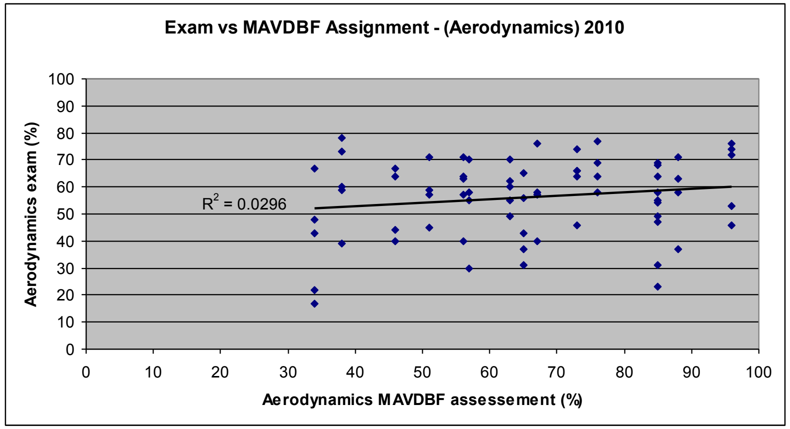

Figure 5. Graph showing individual student performance in the examination for the aerodynamics course and in the MAVDBF assessment for the same course in 2010.

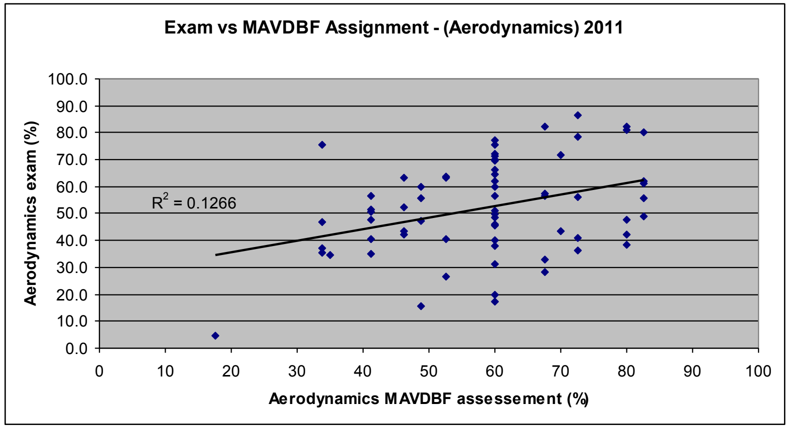

Figure 6. Graph showing individual student performance in the examination for the aerodynamics course and in the MAVDBF assessment for the same course in 2011.

An investigation of team behaviours in the MAVDBF Challenge was conducted in 2011 to accompany the changes to the way in which the project was implemented. The intention of this work was ultimately to understand barriers to performance of design teams and consequently to determine better scaffolding to support development of design team skills within the program. As part of the investigation students were asked to complete a survey focussing on the "team dynamic inventory". Table 2 gives data on positive responses to the various questions obtained from 49 completed survey forms. Each question asked students to rate their team behaviours and personal outcomes on a 6-point Likert scale.

Table 2

Percentage positive responses on the team dynamic inventory

QUESTION on student self-reflection survey (team dynamic inventory)	**POSITIVE RESPONSE RATE**	**DESCRIPTORS OF POSITIVE RESPONSES**
Q1. To what extent did the group have clear objectives and agree upon the factors which should be taken into account in the decisions?	83.3%	Clear, very clear, or completely clear
Q2. To what extent do you think the group allocated its time effectively by planning its work for the period available?	55.1%	Adequate or better
Q3. To what extent did members of the group listen to each other in the discussions?	83.7%	Adequate or better
Q4. To what extent did everyone participate and become involved in the group discussions?	67.3%	Adequate or better
Q5. To what extent was the decision making shared by all members (or was it dominated by one person or a few members of the group)?	65.3%	Some, good, or equal sharing
Q6. How satisfied are you personally with the resulting decisions which the group arrived at?	67.3%	Somewhat satisfied, satisfied or very satisfied

QUESTION on student self-reflection survey (team dynamic inventory)	POSITIVE RESPONSE RATE	DESCRIPTORS OF POSITIVE RESPONSES
1A. How well did the team achieve the task?	79.6%	Well or better
1B. How well did the team function as a team?	71.4%	Well or better
1C. How well did you develop as an individual (learn)	83.7%	Learned a reasonable amount, up to learned a lot

Correlation coefficients were computed to assess the relationships between the nine items on the team dynamic inventory survey. Almost 84% of the students rated learning in the project as significant, and a class-based “focus group” discussion facilitated by an external research assistant not connected with any of the courses showed that students valued PBL as a platform for learning. Despite this positive attitude of students to PBL as a platform for learning the highest statistically significant correlations were only in the range of 28%-34% were found between responses for perceived learning and responses for questions related to time management, team inclusiveness, personal satisfaction with team decisions, and team achievement of goals.

CONCLUSIONS

The MAVDBF Challenge will be continued as a project aiming to provide an integrative platform for learning in the second year of the Aerospace engineering program. The accumulated experience during two implementations suggests the following:

1. Students find open-ended projects to be more challenging than traditional classes.
    a. When managed well by academics, however, students can find such projects to be both motivational and enjoyable.
    b. Students may feel the first such project they encounter to be unreasonably difficult yet learn from the experience so that they are better prepared to undertake more complex projects later in their programs. If this is so, then these skills may be developed through more regular practice involving complex problems.
    c. The learning curve for open-ended projects is steep; students may find themselves more able to perform well if supported by suitable *scaffolding* in programs. Insufficiently developed enabling skills such as time management and team skills may hinder performance of design teams as much as insufficiently developed technical skills.
2. The experience of the MAVDBF Challenge demonstrated the importance of carefully designing both assessment and learning activities.
3. Conducting the MAVDBF Challenge over multiple courses running simultaneously:
    a. Offered the benefit of improved integration of concepts and opportunity for cross-application of skills and techniques, in a way that may be recognised as a good practice by students.
    b. Made close coordination of multiple courses essential.
    c. Created space within the program for a substantial project requiring concerted and relatively concentrated effort by students.
    d. Relies on being able to develop a project that demonstrates good alignment between concurrently delivered courses.

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Biographical Information

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Caleb White is currently employed by Boeing Australia, but during the period relevant to this paper he was a lecturer in the School of Aerospace, Mechanical and Manufacturing Engineering at RMIT. Caleb brought to the work described in this paper many years of experience as an aero-modeller and pilot of radio controlled aircraft, and an enthusiasm for flight that students found infectious.

Roger Hadgraft is Innovation Professor in Engineering Education at RMIT University and an Australian Learning and Teaching Council Discipline Scholar in Engineering and ICT. He has led curriculum change in several engineering disciplines, with a focus on problem/project-based learning (PBL) at RMIT, Monash, and Melbourne Universities. Roger currently leads a new, cross-disciplinary program in Sustainable Systems Engineering and is a Governing Board member of the International Research in Engineering Education Network.

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