

## **BRIDGING THE GAP- AN ACTIVE/INTERACTIVE APPROACH TO INTRODUCTORY AEROSPACE DESIGN EDUCATION**

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**Abstract:** The transition from secondary level classroom-based education to the university experience can prove to be a challenging experience. Many initiatives have highlighted the benefits of engaging students in active learning, and over a number of years, Queen's University Belfast has worked towards embedding this principle into the teaching of Aerospace Design through the CDIO initiative. An introductory module, Introduction to Aerospace Engineering, has been specifically developed to bridge this gap between traditional school-based learning and the independent thought and critical analysis required in the university environment. The module is focused on providing students with a platform to develop a deeper understanding of the theoretical principles of traditional engineering subjects in a hands-on exploratory Aerospace environment. This is aimed at enhancing engagement and enthusiasm of the students for the subject, while simultaneously providing context for some of the more abstract theoretical principles. This paper highlights the ethos behind the structuring of the module, and explores how the active/interactive approach to Aerospace design can enhance the learning experience for the students through the creation of a stimulating environment for engineering discovery.

*Keywords; Aerospace, Design, Education, Problem Based Learning, CDIO*

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### **1. INTRODUCTION**

The concepts of active and interactive learning embedded within engineering education have increased in popularity in recent years due to their potential to enhance the effectiveness of the engineering lecture (Prince, 2004). Active learning is generally regarded as an engagement of students in meaningful activities designed to reinforce and enhance the learning experience, complimented by periods of reflective practice. Interactive learning brings this one step further, initiating a 'partnership in learning' between the learner and both their peers and the academic staff. The ideals of active/interactive learning have been generally accepted as a positive step in engineering education, leading to significant improvements in learner motivation, understanding of principles and application of theories to the development of engineering solutions. It enables an easy accommodation of a range of learning styles as it encourages students to become responsible for their own learning. To this end, the educational process becomes largely student-centred, with academic staff becoming facilitators in the learning process.

However, time constraints and ever-evolving demands for the skills required by graduate engineers can present challenges in embedding some of the more practical elements of engineering into the syllabus. A careful balance of traditional lecture-based material, to ensure

the required depth of knowledge in fundamental disciplines, complimented with sufficient opportunity to demonstrate this knowledge through laboratory and workshop based exercises is often required in order to ensure that students are both technically and practically competent on graduation. While this does not prove difficult for discipline-specific learning, this does lead to challenges in providing environments where students can obtain experience of interdisciplinary design, particularly in the earlier years of the degree courses when students have limited appreciation for the technical competencies contributing to the design process. Opportunities to engage in meaningful design exercises are essential for engineering undergraduates to improve motivation and highlight the practical relevance of the subjects that are being studied within their degree programmes (Prince, 2004, Crawley, 2002, McCartan, 2008). Practical design education also provides a valuable platform to foster creativity and improve student confidence in their engineering ability. To this end, the international CDIO (Conceive, Design, Implement, Operate) initiative presents a philosophy for reforms to engineering education in which technical fundamentals are aligned with practical learning activities (Crawley, 2002). Modern pedagogical approaches and teaching methods are adopted within flexible learning environments to enhance the overall student learning experience. It is based in the idea that reflecting on theory through practice will help to embed principles more effectively than the delivery of theory alone, leading ultimately to a deeper working knowledge of the fundamentals required for future careers.

For Aerospace Engineering, the modern Aerospace industry is evolving at a rapid rate, and it is an increasingly important requirement for graduate engineers to have a deep appreciation of the interdisciplinary nature of the design processes. It can also be argued that engineering is, in a professional capacity, a practical activity, and therefore practical training in the application of engineering theory and methods should be embedded at every level (Vernon, 2000). To achieve this in a structured manner, the transition from secondary to tertiary level education requires careful planning, as many students are unfamiliar with learning which requires this level of interdisciplinary appreciation. Care needs to be taken in ensuring that the student can clearly identify connections between interdisciplinary learning experiences and their own expectations of the degree course (often built from their previous educational experiences), and it should be remembered that many of these expectations are connected to the students' appreciation of the relevance of the subjects they are studying. To ease this transition, a new module 'Introduction to Aerospace Engineering' was incorporated in the BEng/MEng Aerospace Engineering degree programme in Queen's University Belfast to compliment both the learning requirements of a first year Aerospace Engineering student, the CDIO philosophy and the required learning outcomes of UK-SPEC. UK-SPEC defines five main categories of specific learning outcomes required for accredited engineering education (EC-UK, 2008). These are defined as (1) Underpinning science and mathematics, and associated engineering disciplines, (2) Engineering Analysis, (3) Design, (4) Economic, social, and environmental context and (5) Engineering practice.

These SLOs are designed to ensure that engineering graduates are fully equipped for integration into their future professional careers. As a significant portion of introductory engineering education is traditionally focussed on addressing the needs of (i) and partially (ii), a lack of opportunities for addressing (iii) to (v) can exist within Level 1 education (part due to the lack of in-depth technical knowledge of the students at this stage in their education). The design of the introductory course specifically addresses this concern through provision of a number of carefully structured projects introducing theory at appropriate points from the supporting core

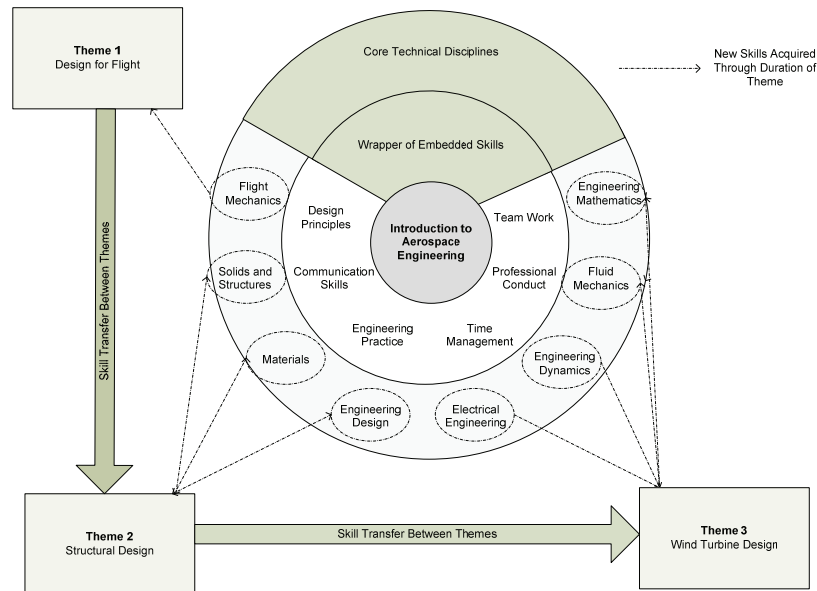
technical disciplines, providing a platform for students to gain familiarity with the principles of design, engineering practice and professional conduct, whilst practicing the fundamental science and analysis presented in the discipline specific courses. The module has been developed as 72 hours of contact time over two semesters, and is taught by two academic staff members with varying interests in both teaching and research in order to ensure that the Level 1 students receive a rounded and balanced introduction to engineering design at an early stage.

## 2. METHODOLOGY

The rationale behind the course design was to develop a framework to showcase the interdisciplinary nature of the design process, and to provide a platform for linking the core disciplines introduced in Level 1 of the BEng/MEng Aerospace Engineering degree programmes. Through a series of structured activities, students are encouraged to engage with engineering practice in a hands-on environment, and develop an appreciation for the design process. This is aimed at ensuring that an attachment of principle to practice in a working engineering environment is developed at an early stage in their education, and to assist in the development of a broad multidisciplinary scientific and engineering background – promoting creativity, innovation and questioning capabilities. While many of these premises are not new (and indeed, there are numerous examples of problem-based learning and design education built around the same premise), the structure has been applied successfully to immediately engage the students in the subject matter. This has manifested itself in greatly improved student attendance (maintaining 95-100% attendance across the full 24 weeks of the course), excellent feedback from the undergraduate students (with an average assessment of 4.2/5 for module satisfaction based on a 16 point assessment criteria), and general continual enthusiasm in class. A large percentage of students entering into the Aerospace Engineering programme at QUB have limited previous experience of aviation, and while they have excellent records of academic achievement, they often have abstract expectations of the technical content of the course. Additionally, students will often have mixed A-Level (or equivalent) subject combinations in their background (all students have A-Level Mathematics or equivalent), so the course is structured to assume a minimal level of prior knowledge, concentrating on learning gained through the syllabus. Ultimately the purpose is to expose student engineers to processes and procedures associated with engineering design. The course is built around a single premise – ***to enthuse and motivate Level 1 students about Aerospace Engineering in an aviation-themed practical environment.***

The educational model has been structured to provide an integrated educational environment with mutually supporting disciplines, explored through a number of aviation-themed projects. Students learn experientially to develop deeper understanding of fundamentals (for instance, Flight Mechanics, Engineering Design, Dynamics and Mathematics), while simultaneously developing skills in Design Principles, Professional Conduct, Time Management, Communication and Team Work (Figure 1). The current Level 1 programme is common to both BEng and MEng cohorts, so there is a need to ensure the course can cater to a wide range of abilities, while providing opportunities for more capable students to further challenge themselves. This is accomplished by open-ended questioning and 'discovery' based challenges, enabling students to explore concepts to a level of depth appropriate to their understanding.

As the main aim of the programme is to provide hands-on experience of the tasks and responsibilities of an engineer, and reinforce the disciplinary knowledge required to execute those tasks, a number of 'real life' exemplars were developed. This was achieved by blending complimentary groups of the technical disciplines from the Level 1 syllabus together to develop learning activities which would reinforce the learning outcomes.



**Figure 1 Introduction to Aerospace Engineering Course Structuring**

Each theme is designed to (a) incorporate the theory introduced in the previous lab, and to (b) introduce new theory from additional modules in the pathway

Through evaluation of the pathway structure, these were grouped into mutually supporting activities under 'themes' – 'Design for Flight', 'Structural Design' and 'Wind Turbine Design' (Figure 1). Each theme is supported through embedded professional skills, engineering practice and design activities, and builds upon the previous theme so that by completion of the module students are fully integrating theory from all eight core disciplines together to develop an engineering solution (Figure 2). The development of these themes can be considered to be a five step process:

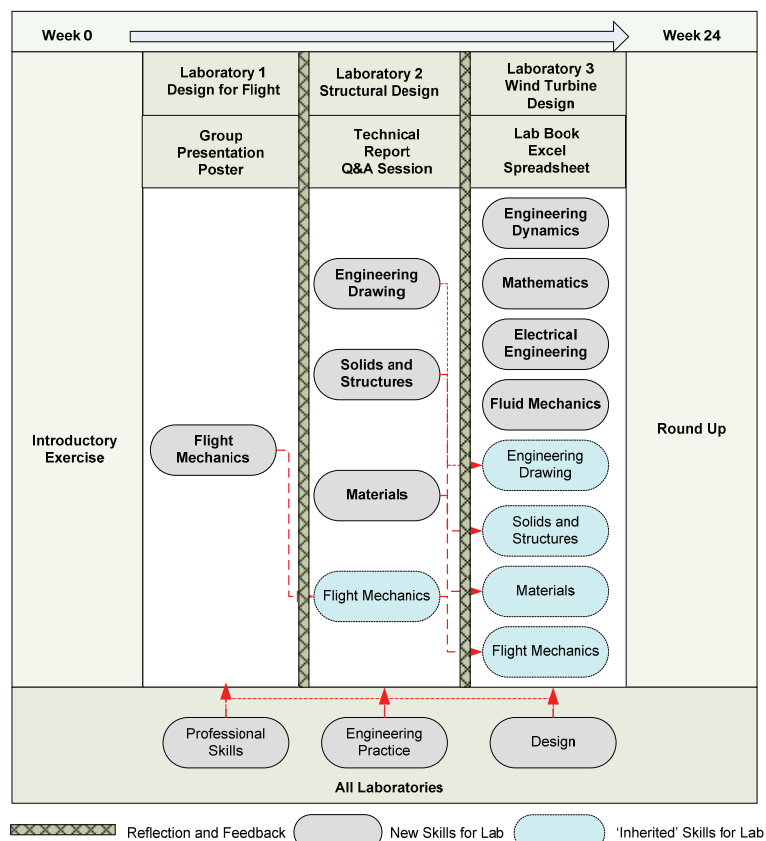
**Step 1 Identify the Drivers** Students will have prior expectations of a course which have driven the initial subject selection. A series of focus groups with current and past students enabled exploration of the expectations of Aerospace Engineering from a student perspective, and as could be expected, a keen interest in aviation and flying was central. In order to transfer that expectation into a motivator, this was used to develop the first key theme (Flight).

**Step 2 Review the Technical Competencies** A review of the technical competencies within 1<sup>st</sup> year was necessary to understanding when key theories are introduced. This was used to provide a basis for the discipline groupings, and determined the timing of the laboratories during the 24 week period. A review of practices (lecture and laboratory-based) was required to ensure that any activities developed provided complimentary learning activities without significant overlap.

**Step 3 Development of Themes** Once viable groupings had been identified, these were further developed into 'themes', ensuring relevancy to both student expectations and overall subject specific learning objectives. These were structured to ensure that students are provided with sufficient hands-on opportunity for learning about interdisciplinary design practices (with sufficient theory in the disciplinary classes to support this), and that the themes 'build' from one another to encourage a process of cyclical learning (Anderson & Krathwohl, 2001) (Figure 2).

**Step 4 Review of Aims and Objectives** As the purpose is to enhance, rather than overlap, with the core disciplines, a review of the learning outcomes of each theme was required. This again ensured that the course would enhance the understanding of key technical principles without introducing significant levels of overlap (and the potential for demotivation).

**Step 5 Evaluation** The new structure was fully evaluated against a series of intended learning outcomes defined through UK-SPEC and the CDIO framework to ensure that the educational outcomes of the course fit with those intended for an accredited engineering degree programme.



**Figure 2 Course structuring for thematic progression**

Once the overall structure was determined, the learning outcomes were mapped to assessment methods to ensure a balance of assessment practices across the course. The assessment reflects that problems do not necessarily have a single 'correct' answer, and is therefore based on performance - willingness to participate, how appropriate information is distilled from technical disciplines and applied to the design problem, and how critical analysis of the proposed solution is undertaken. This represents a major deviation, and is unfamiliar for many Level 1 students. A week of reflection was built-in after each laboratory and assessment, where students are provided

with feedback on their performance, and encouraged to reflect, and identify the areas in which they can improve their design practices, complimented with peer review exercises.

### 3. COURSE EVALUATION

The outline of the Introduction to Aerospace Engineering course at QUB has been introduced, which has been successful in promoting integrated curriculum learning set in a practical environment, complimenting the CDIO principles. Students are encouraged through the exercises to work in groups to solve tangible real world problems, encouraging them to take a greater level of responsibility for their own learning. In doing this, a number of observations have been made:

**Introductory Exercise** The course was initiated through an introductory exercise in Week 0. It was identified as important to 'gain the students attention' as quickly as possible, and this was achieved through a design-build-fly exercise centred on a glider design. This was aimed at increasing student confidence in group work and to introduce some basic terminology associated with aerospace design. While there is no theory to reinforce, the exercise ensured that students were enthused about their choice to study aerospace early on, and introduced team-working. It also helped to introduce the academic staff in a much more informal setting than they would normally, to set the scene for the remaining course.

**Thematic Areas** The selection of the project themes and ensuring a gradual 'building' of material through the module is critical. The students not only gain a deeper appreciation of the technical competencies by not being over-whelmed early in the process, but also are introduced to the truly flexible nature of the engineering skills they are developing and applicability to a wide-range of areas (some of which are outside of the initial narrow view of many student engineers). The initial laboratory examined the consequences of poor design on flight operations using the School flight simulator, simultaneously introducing flight controls and aircraft design, while demonstrating the practical consequences of a poorly conceived design process. As we have found that student engineers often do not fully appreciate the iterative nature of design, a fully looped design-build-test-analyse-redesign-rebuild-retest-reanalyse proved to be an extremely successful next step for the structural design laboratory (in all instances, the students significantly improved their designs on the 2<sup>nd</sup> of these tests through careful analysis and redesign of their structures). This reinforces the idea of there being no single correct answer in an engineering design environment, and that design is a process of trade-offs. The final project, the design of a wind turbine, was selected to introduce some of the less traditional areas in which the skills of an Aerospace Engineer can be employed, embedding concepts of sustainability and social awareness into their learning outcomes, while still providing an environment in which the students could learn about the interdependence of all of the technical disciplines in the Level 1 syllabus. Through a gradual build up, the students were encouraged to use and re-use skills developed in the core modules in their exercises, with less formal guidance given as the modules evolved in order to promote creativity and ownership. It was also noticed that they became more aware of the links between the design exercises and their theoretical modules, were identifying theories/concepts which may help and understand the importance of brining notes from their other classes to the design labs.

**Reflection and Feedback** All students were encouraged to reflect on their performance in the laboratories, introduced in a staged manner. The 1<sup>st</sup> laboratory, due to unfamiliarity of the

students with this type of exercise, was facilitated by the academic staff through questioning, asking them to identify areas of new learning, and how learning from technical disciplines mapped to what they understood about the design process. In the second laboratory, this was extended to students being questioned by classmates about their designs and experience. For the final exercise, the students personally reflected on their performance, and how they could improve both their technical and interpersonal skills in future projects. This reflective practice was complimented with feedback from the staff (both during the laboratories to provide guidance, and also during the question/answer sessions). This not only encouraged personal reflection, but also to promote giving guidance to their peers, based on their own experience. The success of this gradual approach was evident in the written submissions, which evolved from purely factual through to more descriptive, mature evaluations of the work undertaken as the year progressed. To round off, small focus groups were held with the students to compliment the more formal module review processes, in which students were encouraged to identify areas for improvement in both their approach to design, and to the module structuring we have devised.

***Professional Skill Development*** Complimentary development of professional skills - groupwork (exercises are undertaken in teams, and teams rotated), reporting, communication, time management and engineering responsibility are embedded into all of the exercises undertaken during the course to reinforce the professional nature of engineering.

***Inability to function in groups*** One of the major challenges which needs to be overcome is the lack of prior experience in group work the majority of students have. While many of the students are highly capable and can work to a high level autonomously, they struggle with some of the more socially-oriented skills required for professional working environments – in particular time management, conflict resolution, communication skills and the ability to equally distribute workload between group members. This was resolved in the 1<sup>st</sup> exercise by concentrating on the development of these core professional skills integrated with one supporting technical discipline. In most instances, the students demonstrated a greater awareness of how to allocate work between members and communicate more effectively by the 2<sup>nd</sup> project, and the greater sense of community in the teams alleviated most of the time-management and conflict resolution issues. By continuously refreshing the groups, they were provided with multiple opportunities to experience new team formation. By the third exercise, it was clear that the students had a much more mature approach to this and were able to identify the need to assign team roles for themselves with minimal (and in some cases, no) guidance.

***Unfamiliarity with the process of design prior to tertiary level*** Based in many of the preconceptions from secondary level education, students are often focused on the concept of the 'right answer', and many struggle with the idea that there are multiple correct pathways to choose in a design environment. They are unfamiliar with taking initiative, and more at ease with following instructions to develop 'the solution'. Planning actions within design is also not well-formulated, and often the students are not capable of anticipating problems with design or embedding concepts of risk (for instance, assuming that all team members will be available for each week of the project). This was again addressed in the 2<sup>nd</sup> exercise by introducing an iteration into the design process to demonstrate that planning can reduce the number of problems, and that 'emergent' behaviour within the design process is something that they should be aware of (not everything will always go as planned, and that risk analysis is important).

***Uncomfortable with interdisciplinary analysis*** There was limited understanding of how to apply knowledge from a number of disciplines to an engineering design problem. This was facilitated by increasing the number of disciplines required from project to project to prevent overwhelming with the quantity of information they were required to process and to guide them gradually through both technical and professional skill development. By the 3<sup>rd</sup> exercise, students were identifying relevant theoretical concepts from previous/current modules without guidance (understanding that this was expected), indicative of a maturing in their approach.

***Absenteeism and motivation*** Absenteeism and lack of motivation is endemic in Level 1 engineering classes, and can in part be attributed to a complete lack of motivation on the part of the student (something that was widely reported in the focus groups undertaken). However, over the last academic year with the implementation of the new course structure, absenteeism has been reduced to almost zero, with virtually 100% attendance at each class over both semesters. Students have reported enjoying the class, and linked this to their attendance.

***Instructor integration with class*** Through working in a student-centered learning environment, the two lecturers became more aware of many of the learning barriers and issues of individual students, more so than in a normal lecture/laboratory environment. In many instances, issues with individual students were identified more quickly than otherwise would have been, and a higher level of engagement with the students was achieved. This is tightly linked with the need for the supporting academic staff to fully embrace this change of educational environment, again significantly different from that traditionally encountered in Higher Education.

#### 4. CONCLUSIONS

The Introduction to Aerospace Engineering module has successfully provided a platform for students to gain experience of the engineering design process while simultaneously developing an appreciation for some of the challenges which face the professional engineer in their working environment. It has also enabled the lecturers to understand more about the way in which new student engineers assimilate and use engineering information to make judgments in the design process, and how to facilitate increasing the maturity of how they approach this. The model which has been developed progressively introduces students to the ideals of interdisciplinary design while encouraging professional skill development, and fits with the ideals for learning outcomes and programme structuring set out in UK-SPEC and CDIO.

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