Int. J. Engng Ed. Vol. 23, No. 1, pp. 141–149, 2007
Printed in Great Britain.

0949-149X/91 $3.00+0.00

The Self-Regenerating Engineering Design Course: A Top-Down Approach*

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A philosophy for the design and operation of an engineering design course is described. The approach not only ensures an appropriate syllabus and structure with pedagogy well suited to the teaching of design but also ensures that the course is subjected to intrinsic mechanisms that drive it to renew itself continually. The full potential of the Problem Based Learning methodology is realised. The philosophy is demonstrated in an aerospace vehicle design course that has remained effective and successful since 1946.

Keywords: problem based learning; aerospace engineering; educational strategies; design engineer; project based learning; inquiry based learning; cooperative learning; curriculum renewal; transferable skills; staff development; pedagogy; group project; multi-disciplinary; interdisciplinary; scaffolding; engineering heuristics; reflective practice; preliminary design; problem solving

INTRODUCTION

THE TEACHING of engineering design presents a wide range of challenges to University faculty staff. The content of the course, the method of delivery, assessment and required staff skills all present difficulties to the course director. Ensuring reflective practice at individual and team levels requires considerable management and teaching staff effort. Even an appropriate definition of what a design engineer does presents a challenge.

Once operating, courses have a natural tendency to degrade with time either through a failure to evolve or failure to continually repair the effects of the various sources of attrition.

Many courses appear to be deficient in some respects on the basis that industry often finds graduates lacking many of the desired attributes expected in a professional engineer.

ENGINEERING DESIGN

The heuristic and creative processes utilised by the design engineer often lead to the practice being classified as a 'black art'; a fusion of skills, breadth of knowledge and hard earned experience. A succinct definition might be:

> '. . . the use of engineering heuristics to cause the best change in a poorly understood situation within the available resources.'[1]

The role of the design engineer cannot be defined independently from the environment in which he or she has to function. Yes, the engineer must create what did not previously exist but he must achieve this in cooperation with other team members, some engineers, some not, and in cooperation with other teams.

It is often too simplistic to describe many engineering projects as a single, albeit ill-defined, problem. Most requirements lead to a system of systems solution. This implies that the engineer is required to function in an environment that is not only multidisciplinary but is far more extensive in terms of design space.

Magee [2] lists 'desired attributes of an engineer' as:

- A good understanding of engineering science fundamentals (maths, physical/life sciences, IT)
- A good understanding of design and manufacturing processes
- A multi-disciplinary, systems perspective
- A basic understanding of the context in which engineering is practiced
- Good communication skills
- High ethical standards
- An ability to think both critically and creatively—independently and cooperatively
- Curiosity and a desire to learn for life
- A profound understanding of the importance of teamwork.

Many of these attributes are often found to be lacking [3, 4].

Suffice to say that there is a perceived mismatch between the capabilities of engineers graduating from many universities and the demands of industry [5].

* Accepted 6 September 2006.

TRADITIONAL APPROACH TO COURSE SYNTHESIS

The traditional approach to the development of a new course in an engineering, or any other, discipline is to map out a syllabus that will cover, in sufficient breadth and depth, the material that the holder of such a degree would be expected to have assimilated. The material will likely be divided between faculty members according to their specialties. Modules will be devised and sequenced to build from the fundamentals through to advanced topics. Topics will traditionally be assessed through written examinations. In the case of a graduate course this may be supplemented by a research thesis.

One weakness of such an approach is that there is no mechanism to ensure that the ultimate outcome of the course will be a student prepared to meet the demands of industry. Whilst the disparity may not be too apparent in the case of pure science or even engineering analysis disciplines, such as CFD or FEA, in the case of engineering design it usually will be.

First, it is difficult to write a list of modules that, once attended, will achieve the outcome of turning a student into a competent design engineer. Secondly, the approach lends itself to permitting a poor initiation and, in the absence of great discipline and determination, further degradation with time.

Practicalities dictate that the content of the syllabus will be constrained by the interests of the existing faculty members. Furthermore, the detailed content of any particular module is likely to be driven by what is already being delivered to existing courses in related subjects. The scope of material delivered is likely to be dictated by standard quantising of modules (20 hours, 30 hours, etc.) The scope will be further constrained by what can readily be assessed by formal examination and by what faculty members feel comfortable teaching.

In the longer term further attrition can be expected as the content of modules shared with other courses are modified to suit those other courses and as faculty members come and go. Furthermore, there is no intrinsic mechanism to ensure that the taught material continues to be kept up to date and forward looking.

Whilst, the approach is unlikely to score highly in terms of quality education it is possible to minimise the effort required in the design, preparation, delivery and assessment of courses. Courses can flexibly accommodate large or small numbers of students. Courses can be quickly assembled to take advantage of start-up funding opportunities. The approach will be favoured by many academics as it neither requires them to leave their comfort zone nor spend more time than necessary away from research or other activities.

It is quite possible for individual tutors to use problem based learning techniques within the bounds of their individual specialty but without a multi-disciplinary and, preferably, a hierarchical or holistic approach the full potential will not be attained.

THE 'TOP DOWN' PHILOSOPHY

The top down philosophy breaks away from the traditional mind set. It represents a simple but elegant approach, not just to the design of a course but to all its operational aspects. At the heart of the philosophy is the identification of a single (primary) outcome. In this case that of creating an effective, if junior, design engineer. In practice this is likely to be related to a specific branch of engineering such as aerospace.

Whilst it may be accepted that it would be challenging to write an explicit specification detailing all the elements that are required to create a design engineer, it is possible to specify how he would be expected to perform when faced with a real design task in industry. Armed with this understanding of the desired learning outcome it is possible to construct a course with this as the sole objective function.

The natural way to teach is, then, to give the student a representative design task, or 'focal problem', and lead him or her through the process, developing and using the requisite skills and thus building confidence. To achieve the desired ends it is necessary that the design task be fairly sizable.

Of course, the design task is only meaningful when placed in the appropriate context: this context being the opportunities and constraints offered by the industrial environment. The construction of this environment is demanding in terms of imagination and resources, however, its specification is clearly defined and understood as it needs to be a virtual reflection of the real world. The fidelity of this virtual environment will directly influence the learning outcome.

The tutors play an integral part in the environment. Beyond the delivery of traditional lecture modules, the tutors play key roles such as chief engineer, technical specialist, deep generalist, customer and management consultant. It should be noted that the delivery of timely and relevant lecture material plays an important role in supporting the students in their involvement of their design tasks. However, there is no more special significance placed in them than any other supporting resource offered to the students such as industry standard software, laboratory sessions or wind tunnel facilities.

As has already been stated, the virtual environment directly drives the learning outcomes. It is clearly important that the virtual environment is and remains a true representation of industry. Thus, industrial experience of tutors, tutor continued involvement in industry contracts and research and direct industry involvement are all vital to the continued success of the course. This direct involvement also extends to invited participation in the teaching as well as student visits to industry.

The most appropriate approach to assessment derives from the underpinning course philosophy. Thus individual student performance in their design task within the virtual environment is the key performance indicator. Feedback from all stakeholders must not be overlooked if the necessary course evolution is to ensure continued success.

FOCAL PROBLEM

Whilst this element of the philosophy is just another integral component of the virtual environment, it is sufficiently important to warrant separate discussion.

The problem based learning (PBL) approach, whilst first documented relating to medical education at the McMaster University in Canada during the mid-1960s has been practised, in an engineering context, at Cranfield University since 1946 when it was noted as being 'of a kind different from that given at existing institutions' [6].

The general approach has been rigorously discussed in the literature [7–12] and it is not the purpose of this paper to justify its application. The focal problem to be engaged by the students needs to be of sufficient magnitude that it can be decomposed into a small number of multidisciplinary problems, for sub-teams, each of which will then decompose into smaller problems that individual students can take responsibility for.

In the case of aerospace engineering, which is the case study here, an appropriate example is a complete aircraft including airframe structure and systems. However, the approach is equally valid across a wide range of scientific or technical disciplines.

The project needs to be topical, to engage both student and industrial interest, using state of the art technology, to provide demanding challenges to student and faculty members alike, and certainly it needs to be a task that has not previously been tackled on the course to prevent the direct recycling of solutions by staff or students.

It is vitally important to place the focal problem into an appropriate context as this will imply constraints on life cycle issues including cost, social, ethical and environmental.

To start from the conceptual design phase (blank sheet of paper) is felt too demanding a task for the students to begin the learning process. It is more appropriate to start further down the process at the preliminary phase as this enables all of the students to engage rapidly in specific tasks and roles, and develop the required communication structures essential in any team endeavour. The other important implication is that students can immediately be divided into sub-teams that enable close supervision by faculty staff without the level of resources necessary for one-to-one supervision. This initial stage of the course is critical both in terms of student morale, which will set the tone for the duration of the course, and in building and maintaining momentum. This momentum is regarded as a key parameter in peer and self learning as well as reducing supervision workloads (the two being interrelated).

The disadvantage of starting from the preliminary phase is that the conceptual design phase must be completed by faculty staff prior to the commencement of the course. This and the compilation of supporting data is a significant resource commitment. The preparation needs to be fairly rigorous to ensure that the project progresses smoothly. There will be little time to rectify errors once term starts and any delays will inevitably destroy project momentum and lose precious days or weeks that are needed for key milestones to be reached. From an educational point of view, a further disadvantage of starting from the preliminary design phase is that the students miss the experience of synthesising, in this case, an aircraft starting only from an outline requirement. Whilst each student will go through a conceptual design process for their particular component on the aircraft, the experience is not quite the same as developing the overall system concept. (In fact, at Cranfield, the students are offered this opportunity during a separate element of the course.)

Whilst the design cycle does not start from the conceptual design, it is important that attention is drawn to where appropriate solutions may involve modifications to the concept in further iterations.

The end point of this engineering design project is the generation of a system of integrated design solutions that are validated through appropriate analysis and or test and communicated through reports, presentations, engineering drawings, and virtual and physical models. In practice this equates to a point slightly beyond the preliminary design phase and part way into the detail design phase of the traditional design cycle.

A VIRTUAL ENVIRONMENT

The selection, scope and design of the focal problem are critical to the learning outcomes of the course. It is the central feature of the virtual industrial environment that the course is structured around. However, it is just as important that the remainder of the environment be correct or the learning outcomes will not be as desired.

The philosophy here is simple: recreate the environment that a design engineer will encounter in industry. The more representative the environment, the more precise will be the learning outcome.

The two elements to be considered here are the specification of the environment and the resources required to create and maintain it. The former is a known quantity. Faculty staff with industrial experience and with close links with industry through consultancy, contracts and research and industrial advisory committees can develop the specification. The later is a departmental matter. It is an accepted fact that all design courses are very resource intensive [13]. Staff time is likely to be the greatest burden, although software licences and support will also add to the cost.

The main elements that form the framework of the environment are as follows:

- The focal design problem
- Key milestones for specific deliverables
- Allocation of specific roles and responsibilities to individual students
- Allocation of students to specific sub-teams with specific responsibilities
- Allocation of specific roles and responsibilities to faculty staff members
- Appropriately qualified tutor support (discussed later)
- Additional industrial support as appropriate
- Access to and support for industry standard software and other tools
- A framework of formal design reviews analogous to an industrial 'gated' design process including a final critical design review (CDR)
- A framework of weekly informal, but structured, design review meetings for the team and sub-teams
- Timely site visits to manufacturers' facilities and to operators/customers
- Rules and regulations existing to ensure safe professional standards are maintained. In this case the current airworthiness requirements appropriate to the class of vehicle considered will be enforced.

TUTOR SUPPORT

The part played by the faculty staff in the operation of the course and, in particular, the running of the project is critical and deficiencies cannot be made good solely by augmenting staff with industrial input. The majority of staff needs current industrial experience, either through recent employment and/or through ongoing consultancy or contract work. Furthermore, a solid core of the teaching team must have had experience of running such a project and environment (else significant 'teething' problems should be anticipated).

In general terms, the importance of the staff's role in positively modifying student behaviour in the design environment cannot be overstated and is further discussed by Koen [14].

As with the students, staff are allocated specific roles and responsibilities. Some play the part of technical specialists who are on hand to advise on specific technical issues and analysis techniques. Access is primarily through the weekly meetings but also, subject to availability, at other times during the week. This ensures that work progresses at a steady pace rather than staccato in phase with the weekly meetings. Questions put to these team members may come from fellow staff as well as students.

Other staff members are required with deep generalist skills. Good staff in this category are a scarce commodity in academia. Their primary role is to lead the team, sub-teams and individual students through the hierarchical multi-disciplinary problem solving process. Their input will become progressively lighter-touch as the project proceeds. Some discussion on this matter is offered by Vesilind [15] and in the broader sense by Fink *et al.* [16]. Practice is always demonstrated with current issues relating to the focal problem and, where possible, in front of the whole team whether or not the specifics are relevant to every individual. The first law of problem solving (understand the problem) is of particular importance where some students possess English as a second language. Although it is accepted that problem solving can, to some degree, be formally taught [17], learning (and teaching) by doing seems to be considerably more effective. Problems that the students do not naturally identify are highlighted and multidisciplinary links and relationships between concurrent problems are pointed out. Similarly, trade-offs and balances between aspects of potential solutions are indicated. There is a significant difference between the problem solving approach of professional engineers and that of students [18]. This needs to be imparted to the students by the practitioners.

The secondary, though still vitally important, role of the deep generalists is to fill in the inevitable gaps in the collective skills and knowledge of the team and otherwise illustrate safe and professional ways to proceed in the case of incomplete or absent information. The demonstration of engineering heuristics plays an important role in the procedures.

To complete the virtual environment it is necessary to designate one individual to act in the role of chief engineer. There will be frequent occasions when decisions and compromises do not form naturally and a resolution needs to be reached to enable progress. In this event it is useful to have an individual to adjudicate to ensure that a consistent vision for the project is maintained. It is unlikely that any student would have the experience to fulfil this role and so an experienced faculty member is required.

Placing a faculty member in the position of Chief Engineer does come at the cost of denying a student the educational opportunities presented by fulfilling such a role. Furthermore, placing students in key positions gives the students a feel of greater ownership over the project and helps develop the confidence of the individuals and the team. Thus all other management roles are given to the students including two programme managers (who front weekly design meetings, rather than the Chief Engineer), configuration control, airworthiness, mass monitoring etc.

A key feature of the philosophy is that the staff are as new to the focal project as are the students. They have no 'special access' to the correct solution, as none exists, and will be equally challenged by the task. This helps to turn the student-teacher relationship into a peer relationship, encourages students to rise to the challenge (rather than fostering a reliance on the staff to always take the lead) and makes for a more representative working environment.

An additional task for all staff members is to keep the game play within the bounds of the virtual environment by, for example, offering alternative or heuristic approaches to problems that might, in industry, be solved by resource critical methods. Similarly, advice is given to restrict students from repetitive tasks that, whilst necessary in industry, do not contribute significantly to the learning experience.

Formal lectures do play a part in supporting the focal project, though are not an end in themselves. It is assumed that the analytical fundamentals of engineering as well as wider contextual material will have been covered, possibly in a more traditional manner, prior to participation in this programme. Additional, lecture material is delivered, some of which, though in specialist or advanced topics, will be extensive in scope to meet 'real world' needs rather than restrictive to enable a formal examination to be attempted. This forms an ideal basis for students to supplement their 'bigger picture' understanding with in depth further study where desired or where demanded by the needs of the project. In many cases assimilation of the material is by application on the project.

McMaster and Ford [19] discuss the issues surrounding 'who should teach design?' and the obstacles they face. Some of these issues are summarised here.

- Teaching design well requires a significant amount of design experience and a generalist's knowledge of many disciplines. Many years of experience are required to prepare even the fastest learner.
- Design has rarely been recognised as a bona fide research discipline and consequently is rarely allowed to generate the technical journal papers demanded for career progression.
- The labour intensive nature of design teaching restricts participation in sponsored research.
- Individuals with real design talent generally find greater rewards for their abilities in industry.
- There are not enough qualified engineering design professors in our universities today and little opportunity or incentive to provide replacements.

The most dedicated of university educators find themselves in an environment that does not reward the effective teaching of design engineering [20, 21].

INDUSTRIAL STEERING

An industrial steering committee is an important element of operating the course. Though only meeting perhaps twice per year, this is sufficient to ensure that strategic aims are kept in step with the industry view and that the virtual environment maintains fidelity.

PRACTITIONER SEMINARS/VISITS

Although teaching staff will have recent industrial experience, it is unlikely to be directly related to the current focal problem in any given academic year particularly across a wide range of disciplines. Thus it will always be desirable to have seminars at appropriate phases of the programme given by senior practitioners directly involved in analogous current industrial projects. Informality ensures that these engineers do not have to invest much time in preparation (1: they are busy people, 2: the annually changing nature of the focal problem implies that they will only be invited the once) and enables the students to make maximum use of their specialist knowledge as applied to the focal problem. Informed discussions can make a significant impact on student design work. During such seminars students will often acquire contact details of further practitioners from other disciplines.

FEEDBACK

Whilst all courses benefit from structured feedback processes, such as regular feedback pro forma, the course philosophy ensures that staff receive continuous direct or implied feedback relevant to their contribution to the course.

The support given to the students by academic staff is primarily aimed at enabling them to fulfil their responsibilities on the focal project. Where a student is unable to make progress on a particular aspect of the design problem due to some deficiency in knowledge or skills, support is given by an appropriate member of staff. Where a number of students repeatedly seek assistance on a common aspect, staff are driven to adapt their teaching (by way of content or delivery) to redress the deficiency. Thus the focal problem creates a mechanism for self repair.

The significance of this intrinsic mechanism is discussed later in the paper.

ASSESSMENT

Assessment by written examination is an approach that is often used at the undergraduate level and may be a suitable method for ascertaining the level of knowledge assimilated. Experience indicates that the learning process resulting from this form of assessment tends to focus purely upon the student's survival of an encounter with an exam paper. In considering the 'traditional' lecture module/examination approach Camp [22] states that 'Too many students memorize, forget, fail to apply or integrate knowledge, and resist further learning'.

In any case, assessment by traditional means is not appropriate here as it is not possible to evaluate a student's ability as a design engineer through a formal examination or assignment. The discipline is too multifaceted and the ability simply to supply the expected answer to a fundamental question reveals little. As commented by Shuman *et al.* [23] on engineering ethics 'even if the student provides a creative solution to a posed ethical dilemma, there is no assurance that he or she would could carry that solution to completion in practice'.

However, the issue of determining the performance of a student in a real situation is straightforward as the key feature of the course is the virtual industrial environment designed specifically to enable this. Thus assessment can be achieved by observing student performance on the focal design problem. The specific elements of this will include assessment of technical reports, engineering drawings, viva voce, peer assessment, performance in formal technical presentations etc. In the majority of cases students will exceed the criteria in each element of the assessment and achieve a required overall pass. In borderline cases a meta analysis of the resulting data enables the board of examiners to recommend, or not, satisfactory performance. On triangulation, Felder and Brent [24] suggest that the more tools used to assess a specific programme outcome or learning objective, the greater the likelihood that the assessment will be both valid and reliable.

PEDAGOGY

The underpinning theory is widely discussed under the headings of Problem Based Learning, Project Based Learning, Inquiry Based Learning and Cooperative Learning.

The foundation of the approach can be viewed through constructivism and constructionism theory where we must assume that whilst the students will all, by this stage in their careers, have reasonably sound knowledge bases; these will be interpreted through personal perception resulting from their individual educational, and life, experiences. This basis must be built upon, interdisciplinary links reinforced and the necessary new skill set developed.

The approach to teaching is intended to exercise the students through all six levels of Bloom's taxonomy of the cognitive domain [25].

6 Evaluation (Ability to appraise worth of solution)
5 Synthesis (Ability to combine separate elements into new solution)
4 Analysis (Ability to decompose problem into constituent parts and establish relationships between them)
3 Application (Ability to apply in novel situations)
2 Manipulation (Ability to rephrase knowledge)
1 Knowledge (That which can be recalled)

Traditional lectures and other activities contribute at level 1 and the group activities extend the students up to level 6.

Cooperative Learning is characterised [26, 27] as encouraging positive interdependence between students relying upon one another to work towards a common goal yet with individual accountability for specific roles within the team.

It is recognised that, across the entire age range, individuals learn best in the construction of an artefact that is personally meaningful, shared with others and is reflected upon. In this situation the student is more likely to become engaged in the learning. Here the artefact or artefacts are hierarchical such as a piece of analysis, a component design, a subsystem, a system . . . At the highest level the artefact is, of course, the Focal Problem.

Common features [28, 29] of all project-based learning models can be mapped from the approach suggested here:

1. An introduction to anchor the activity—A faculty member introduces the focal problem, places it in context and makes best effort to 'sell' the concept to the class.
2. A task—this, of course, is the focal problem.
3. A process that results in one or more sharable artefacts-the role of the design engineer.
4. Resources—this is represented by elements of the virtual environment.
5. Scaffolding—achieved through the faculty members supporting the activity.
6. Collaborations—by the nature of the team work. Interactions between students and between students and staff.
7. Opportunities for reflection and transfer—the ongoing process of design reviews, peer interactions, documentation and formal presentations.

For element (2), the task, to be adequate it is important that it is sufficiently ill-structured. Formally the features of an ill-structured problem can be summarised as [30] follows.

- It requires more information for understanding the problem than is initially available.
- It contains multiple solution paths.
- It changes as new information is obtained.
- It prevents students from knowing that they have made the 'right' decision.
- It generates interest and controversy and causes the learner to ask questions.
- It is open-ended and complex enough to require collaboration and thinking beyond recall.
- It contains content that is authentic to the discipline.

The importance of element (5), the scaffolding, is discussed by Greening [31] and Barrows [32]. The support must help develop skills in problem solving, metacognition, critical thinking, self directed learning etc.

The resulting approach to teaching on the course is highly learner centred. Sitting at the heart of the extensive learning infrastructure is the student whose actions facilitate his or her education and that of his or her peers. There is considerable individualisation of the learning experience across any given cohort. Beyond this, the process drives the development of the course and provides stimulation for staff reflective practice. The multifaceted nature of PBL drives staff to use a variety of approaches to teaching. This is important in that it forces staff to use teaching styles that are uncomfortable to their specific Myers–Briggs Type Indicator (MBTI) [33, 34] categorisation. Although challenging to the staff, this ensures that all student learning types will benefit.

The concept of each student having a specific area of responsibility is important. This not only ensures division of labour but also drives each student to interact with the rest of the team. Whilst it is accepted that weak students will impact on the progress of the team as a whole, this merely reflects a natural aspect of team working. Sortland [35] discusses the benefits of the 'experts-in-team' concept; however, here we augment the team with a greater degree of technical support from faculty members, certainly in the early stages of the project.

MECHANICS OF AUTO-RENEWAL

There has, is and always will be a need for curriculum renewal in the field of engineering design. Reasons are many and include the continuous, if not accelerating, technological advances, the ever-changing political climate and environmental concerns [36, 37].

The course philosophy, as described in the earlier sections of this paper, not only addresses curriculum issues but the entire teaching environment.

There are a number of factors deterring effective curriculum renewal:

1. Identification of requirements. It takes considerable effort to monitor continually the needs of industry and the potential professional engineer. This must be continuously mapped against the elements of the course to enable the development of deficiencies.
2. Dissemination of faculty staff. Once required changes to the curriculum have been identified they need to be made specific and disseminated to the appropriate members of staff.
3. Motivation of faculty staff. Revision of teaching material can require considerable effort which detracts from other activities such as research and contract work.
4. New material must be implemented into the teaching activities of faculty staff.
5. It is important to assess the effectiveness of changes to the curriculum. Design of the assessment method requires care to ensure that the desired outcomes are achieved.

Each of these aspects is addressed (referring, where appropriate, to earlier sections in UPPER CASE) as follows:

1. The philosophy fulfils this need partly through direct efforts of faculty staff (See section on TUTOR SUPPORT) and the Industrial Advisory Committee, as many courses do, (INDUSTRIAL STEERING) but mainly through the selection of timely, cutting-edge, challenging focal problems (FOCAL PROBLEM). These challenges are directly representative of what industry and operators are looking at now or will be looking at soon.

   As the faculty staff will play an integral part in designing the solution to the problem it becomes an integral part of their role to ensure their contribution is up-to-date and appropriate. This, of course, feeds directly into their teaching whether through formal lectures or informal support.

   Furthermore, the design problem chosen will also drive the need for modern engineering tools which in turn drives the development of the virtual industrial environment.
2. Due to the nature of the 'FEEDBACK' aspect of the course philosophy outlined here it can be seen that the mechanics of the course delivers the requirements directly to the staff concerned. It happens in a direct and natural manner that does not require imposition by the course management and thus is not a source of conflict within the teaching team.
3. The need to be able to support the students in the focal problem requires faculty staff to remain 'on top' of their subject. The fact that the problem is always selected to be 'cutting-edge' ensures that staff are continuously exposed to new and challenging issues. The immediacy of the need and challenging nature of the task acts as an incentive for staff to explore new ground driven by their curiosity. Furthermore, the continuous nature of this mechanism ensures that progress is made throughout the year thus avoiding a situation where updating material becomes a task in itself. In many cases the updating takes the form of staff simply developing their knowledge and understanding of its application.
4. Any updated teaching and support material will be brought into action immediately as it is the urgent need of the group work that will have driven its creation.
5. The aspects of the 'FOCAL PROBLEM', 'TUTOR SUPPORT' and 'FEEDBACK' of

the course philosophy are such that the effective introduction of curriculum changes will generate immediate positive feedback via student performance on the focal problem. Deficiencies in the curriculum will be clearly indicated by cavities in the students' solutions to the focal problem. During the regular project review meetings (weekly) staff will see these holes begin to form, thus enabling remedial action (via curriculum review and augmentation) to be taken immediately. Where this continuous process works all cavities should be healed by the completion of the focal problem.

CONCLUDING REMARKS

The basic top-down philosophy that underpins this aerospace design course is described here generically since it can be implemented into any engineering course and could also be applicable to other scientific based subjects. The approach gives a team of students an engineering problem to solve within the setting of a representative virtual industrial environment. A number of professional engineers, as part of the environment, lead the team through the task which is as new to them as it is to the students. The performance of the students in their design task is the key performance indicator with regard to assessment.

As the task and the environment are fully representative of the real world and 'state of the art', the faculty staff are driven to ensure that both their personal expertise and their formal teaching material are up to date and forward looking. This intrinsic mechanism drives the continual renewal of the course, the virtual environment and the new project for each intake.

This self perpetuating operational cycle represents what is referred to as the 'course philosophy' and is described as 'top-down' as the course content is entirely self defined from the single requirement to develop competent practising design engineers. The operational cycle has been shown to ensure that the course will never stagnate, lose its edge or excitement. The effectiveness of the approach and in particular, its ability to continually renew itself, is apparent in its exceptional longevity. The course has run successfully since 1946 (outlasting many course directors) and has since spawned parallel courses in aircraft engineering and astronautics and space engineering.

Perhaps a simple analogy might be that planning a course with this philosophy is like pre-visualising the teaching team at the summit of a mountain and planning the expedition backwards in time towards base camp. This ensures the best possible chance of reaching the desired goal. The traditional approach might be analogous to the teaching team attempting their individual segments of the climb on different days and, likely, on different mountains.

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