

## PROJECT ORIENTED LEARNING – A VEHICLE FOR TEACHING SYSTEMS INTEGRATION

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**Abstract** Student engineering projects are an important learning environment for developing a student's understanding and experience of how products and services are designed and integrated to meet performance, time and cost demands typical of present-day markets. A development programme is underway to create a blended learning system that will support the execution of these student projects in the University of Hertfordshire's School of Engineering and Technology. Its goals are to expand the range of learning benefits, use resources to better effect, and demonstrably satisfy achievement targets set by the university, engineering professional bodies and prospective employers of graduates. The design principles that underlie the approach taken in order to create this learning system, the attendant practicalities that need to be resolved and the nature of the anticipated outcomes are presented. Of significance to the blended learning community is the use of a relevant methodology, borrowed from the industrial arena of complex systems design. This is highlighting the value of strong formalisation and the observance of explicit processes during the design, integration and application of a blended learning system.

### An opportunity for change

This paper describes the systematic approach being followed in order to understand the needs of all stakeholders in an existing programme of team-based, multi-disciplinary engineering projects, and how the design of a blended learning system that meets these needs is being undertaken. The paper is by way of a status report approaching halfway through a 2-year activity, with roll out commencing October 2010 and full capability by October 2011. Its approach is considered to be of interest to the blended learning community since it follows a well-established methodology borrowed from engineering design.

Projects such as the design and development of Formula Student cars or Autonomous Unmanned Aerial Vehicles are important tools for developing students' experience of system design and integration, and also for providing experience of working in a team to meet technical, time and cost targets. Projects of this nature are an important part of the final year of MEng/BEng degrees in the School of Engineering and Technology at the University of Hertfordshire. This initiative to create a blended learning system was prompted by the normal periodic review of the goals, the teaching strategy and the resource plans for any teaching module in the university.



Figure 1: UH FS2008 class 1A team

The learning opportunities presented by the rich environment of challenges and experiences seen in student engineering projects have long been recognised to favour a constructivist and experiential model of learning. However, there was growing evidence that different teaching regimes could be applied both in the preparation for, and during the conduct of, student projects. In varying measure complementary learning approaches had been informally employed, but not according to an explicit strategy having uniform and mutual benefit across all projects.



Figure 2: FS2008 class 1A construction

From the outset it was decided that beneficial outcomes for students and staff could be achieved by blending fresh media, techniques and material with existing approaches. Consequently, by merging a variety of pedagogical techniques, a blended learning model was sought such that it could meet the contrasting needs of all the parties involved throughout the life of these engineering projects. The aim is to create an optimised, seamless, blended learning solution; one that is traceably developed according to the goals and requirements of those who direct, supervise, undertake and assess student projects.

Beyond being an opportunity to refresh previously taught knowledge and introduce additional skills, the intent has been to shift the nature, balance and effective use of teaching resources, and thereby to provide a better range of engineering, business, individual and society-oriented learning outcomes for students. A particular goal is to maximise the crucial asynchronous, face-to-face teaching contact that is seen to have high learning value throughout the dynamic and sometimes unpredictable course of a project.

A sufficient diversity of teaching media, techniques and technologies has evolved in recent years such that Kuhn's term paradigm shift (Kuhn, 1962) now aptly applies to the educational regime called blended learning. Paradigm shifts are generally all pervasive and it seemed not just opportunistic but obligatory to examine the impact of blended learning – to examine a directed shift “from comparison and replacement to analysis and integration” (Goodyear, 2008); that is, to fundamentally and rationally redesign, rather than merely augment present practice.

Creating novelty through “analysis and integration” is stock in trade for engineers and for those who teach engineering. Thus by viewing a blended learning opportunity as the design and integration of a system – a learning system – that could traceably meet a well-formed set of requirements, the task took on a familiar face. In consequence, the nature of a problem-driven, compositionally diverse, yet strongly coupled teaching solution readily suggested the application of a disciplined structure that is now routinely applied by high-technology industries during their design and construction of complex engineering products and services.

### The domain of use

The University of Hertfordshire have taken part in Formula Student for over 10 years with significant success (<http://www.racing.herts.ac.uk>). It is now world wide with thousands of students taking part



Figure 3: FS Germany 2009

in the design, construction and racing of cars with strict rules in the same way as Formula 1 racing operates. UH has had significant success over the years, producing the top UK car on several occasions and taking part in the USA, Australia and German versions of the competition.

Academically there is much to be gained from taking part in competitions such as Formula Student. Students develop team working skills, leadership and time management skills. They are expected to demonstrate their business and

marketing ability, in addition to the core activity of innovative design, quality production and the obvious performance issues associated with the motorsport industry. The practical nature and competitive nature of Formula Student is highly motivational and develops in the students a highly productive work ethic which naturally transfers to their more academic studies. It makes the students highly employable and most of these students have been offered multiple jobs by the leading motorsport companies on completion of their studies.



**Figure 4:** UH student discussion with Damon Hill OBE, ex-Formula 1 driver



**Figure 5:** UH FS2009 class 1A Car

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In the past three years the entries into the Formula Student class 1A competition have been the focus for one of the MEng final year Team Projects involving the design of cars using alternative power. Students have developed the first ever hydrogen powered entry and the first ever all electric racing car that outperformed most of the conventional petrol driven cars in the main competition. Both cars won their respective competitions in 2009, hoping to repeat the success in

July 2010.

The benefits of the Formula Student projects are now being expanded to other projects as the number of students taking the MEng at UH has expanded. Projects such as the Unmanned Aerial Vehicles and a Rocket Powered Sled (<http://www.rockets.herts.ac.uk>) for impact testing have posed similar challenges for aerospace students. Design of a futuristic Armoured Personnel Carrier for BAE Systems and the development of a fuel efficient and reduced audio pollution hovercraft (<http://hovercraft.herts.ac.uk>) have challenged students studying Mechanical Engineering.



**Figure 6:** UH Rocket Test Sled 2009

The MEng Team Project is an essential part of the degree programme necessary and satisfies the learning outcomes defined by the IMechE for an accredited MEng engineering degree. The projects currently represent 25% of the final year studies and teams vary in size from 3 to 10 students depending upon the nature of the project and mix of students from different engineering disciplines. Officially there are two members of staff supervising these projects but other staff do

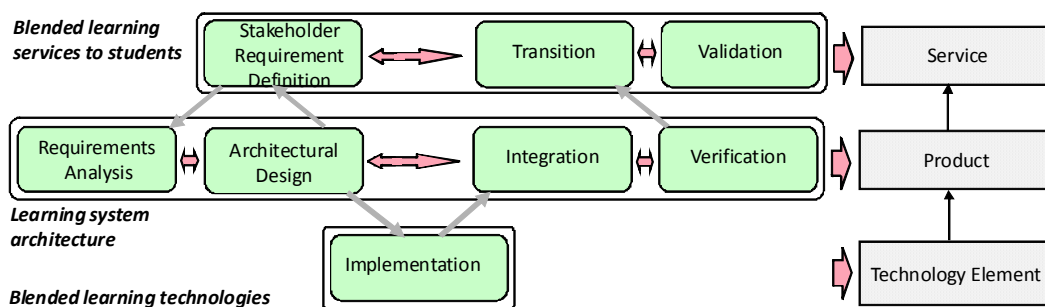
act as advisors to students when necessary. The one thing all projects have in common is that they all challenge the students to work together to solve an engineering problem that is beyond their previous experience.

### The adoption of a disciplined design methodology

Given the nature of this environment of use and the opportunity for a radical re-assessment of learning options, it was decided to approach the definition of the problem, the design of a solution and the integration of its implemented components according to disciplined engineering system design principles and practice. Essentially, it follows a system approach (Ramo, 1998) whereby the integration of heterogeneous elements of technology, each with their individual strengths, is architected to form a homogeneous unity with novel emergent properties and behaviours that traceably meet a range of agreed needs of stakeholders. Such a design scheme appeared to accord with the goals, characteristics and realisation practicalities of a blended learning system.

Although the engineering background of staff engaged in devising and delivering a solution was naturally attuned to such an approach, it is the underlying power, generality and transferability of this system approach that really commends a strategy whereby engineering design method is migrated to the design of a teaching/blended learning system. In particular, the processes used for creating and utilising coherent, multi-technology engineering systems appeared to offer real advantage for devising and employing a multi-medium system of teaching.

These processes, together with their corresponding practices, have evolved with increasing formality for over a half a century and they can now be seen to underlie most, if not all branches of engineering and technology. Helpfully, the processes have been refined and codified in a domain-neutral way by the international community, and in their form as an ISO standard on system life cycle management (BSI, 2002) they were adopted by this initiative to govern the procedure and decision making applied to the blended learning system design. In addition, a valuable raft of techniques and methods has arisen to support the effective execution of these processes.



**Figure 7:** Primary Processes (BSI, 2002) Governing the Blended Learning System Design

The flow of this system-oriented way of tackling problems is illustrated in Figure 7. It shows how there is:

- a top-level pull coming from an understanding of the services needed by stakeholders;
- a bottom-up push from the available modes of learning offered by different technologies;
- a creative mediation between these, that analyses and synthesises the functional and

physical views of the architecture of the integrated learning product.

It is important to recognise there is no precedence in the influence of these effects: need, architecture and implementation technologies are concurrent agents in the formulation and execution of a solution. Nevertheless, logically the flow is easier to understand in the top to bottom sequence of Figure 7, and this programme of work is therefore presented correspondingly.

### **Understanding the problem**

The collection and structuring of needs in Figure 7 followed the recommended pattern of defining stakeholder requirements in (BSI, 2002): understand the different classes of stakeholder in the student projects; employ appropriate techniques to elicit unbiased needs and constraints on a solution from representatives of each stakeholder class; define a compliant set of delivered services and candidate user interactions, resolve conflicts, ambiguity and inconsistency; and close the requirements loop by confirming their adequacy with stakeholders. Despite the challenging liaison and level of effort that has been required to interact with all stakeholder classes, this pattern of action has led to a sound point of reference for managing the whole endeavour, and for establishing criteria that will indicate the acceptability of the resulting blended learning system.

Interviews, group sessions, written submissions, and governing policies and regulations all went into the requirements melting pot, with inputs ranging from Head of School, project supervisors, planners, teaching resource providers, assessors, students, accrediting professional bodies and representative employers of graduates. Out of this came a de-conflicted and rationalised set of requirements. Key features of this were:

- the value of e-learning to asynchronously provide pre- and in-project understanding, and so match the patterns of individual student need and avoid burdening staff with mechanistic teaching tasks;
- the need to maximise responsive contact time of project supervisors as and when learning opportunities are presented by project situations;
- the importance of revitalising previous tuition by illustrating its project relevance and impending contextual application;
- the need to synchronise key learning situations with the unfolding critical steps of each project, rather than be constrained by the prescription of timetables;
- the availability of exemplars to illustrate decision-making issues and options, and to reinforce the experienced guidance provided by staff at critical points in a project.
- the appreciation that team working practices and interpersonal skills are necessary project enablers and of enduring career benefit;
- the recognition that knowledge and practical understanding of the project environment significantly improves graduate value and employability;
- the need to facilitate or refresh training on specific tools that are essential for project execution;
- the value of a sense of personal achievement and confidence building that can come from the project experience;
- the benefit of effectively sharing group and individual learning and experiences, within each project and across all projects.

Thus, ahead of proposing any solution or implementation strategy, these (and other) requirements established the goals and subsequent achievement indicators of a blended learning system for student engineering projects.

### Functionally analysing a solution

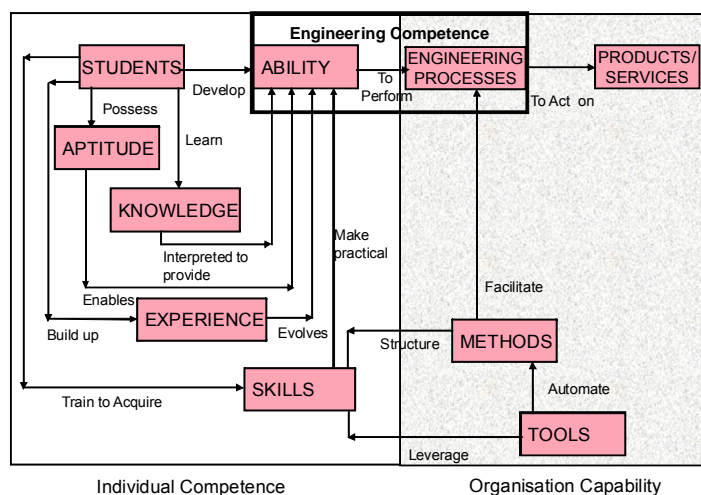
From these stakeholder needs, and together with the limitations of unavoidable constraints and practical restrictions, the design team formulated a functional picture of the required learning system. By studying:

- the nature and characteristics of different modes of teaching and learning;
- which attributes of each learning mode related to the needs of the solution;
- the reports of educationalists on the strengths and weaknesses of each mode in different situations;

a set of models of functional and behavioural characteristics was built in order to relate viable options to the rationalised set of needs for a working solution. This relied largely on commonly used types of engineering system representation: graphical structuring of ideas using 'mindmaps', data flow/entity relationship maps, N2 Charts showing primary associations between functional attributes, the so-called House of Quality that presented the assessed values of the relationships between requirements and functions, and sets of matrices to interrelate functional attributes. In addition, the traditional (and necessary) backstop of natural language descriptions was used for more complex or subjective analysis.

Using these basic methods of systems analysis, and with support from tools to provide structured presentation, it was possible to build the many facets of a solution expressed in functional terms. Beyond being the media for disciplined documentation of problem understanding and functional solution formulation, these models act as a mechanism to share the creative flow within the design team. Furthermore, through their improvement of communication generally, they are assisting verification and refinement of the problem with stakeholders, and assessment of the merits of candidate solutions.

Figures 8 & 9 are illustrative of this functional analysis. They present some of the issues and associated trade-offs that govern selection of candidate learning components, together with the roles, relationships and influences in an implemented solution.



**Figure 8:** Functional Entity Model of Learning Components that Deliver Competence

The power and simplicity of the model in Figure 2 has helped the design team to conceptualise how a blend of learning functions can provide a rounded and balanced learning system. It is a variant of a competence model in which the left side is concerned with learning and the individual, and the right side with the application domain and its resources (Arnold, 2000). Interestingly, the discrete skill component that draws on processes, methods and tools is important to engineering learning (and probably many other disciplines given the leverage available from today's technology). It is not presented with this distinction in the Dreyfus (Dreyfus, 1986), Bloom (Bloom, 1956) or many learning/competence development models, so this representation has provided a better functional reference for the task in hand.

It is of note that, despite its many and varied interpretations, the Dreyfus learning model confirms the high value of student projects in an engineering curriculum. Its third step of learning progression – the Competent level – is characterised by facts, rules, selected contexts and accountability. The engineering projects have proved to be ideal situations for presenting these last two learning criteria, since they address novel product/service challenges and offer a range of accountability opportunities that can be assigned according to student interest and aptitude, e.g. marketing, planning, finance, technical leadership. Indeed, since the project presents the need to see situations holistically, to extract what is important and to employ rules out of context, students can demonstrate their progress towards the criteria of the Proficient level.

The dimension of aptitude in Figure 8 may at face value appear to be a pre-ordained factor in a learning situation. However, in practice there is much to be learned by a student about their strengths and weaknesses (either by introspection or mentoring). Aptitude awareness is seen to be an important factor for on-going self-development and for future job satisfaction, and it is a valuable learning outcome from project participation. Accordingly, lectures, workshops and on-line assessments concerned with factors such as communication, leadership, influencing and teaming are expected to play a part in achieving effective team formation – all acknowledged influences on the value of the project experience.

Figures 9 and 10 are representative of other models developed to understand the primary functional variables and their attributes. Many such models that can be built (see for example (Botturi, 2006, Figure 7) using different notations to address different concerns, and each brings further understanding about the functional complexity of a resulting system's architecture – a principle that emerges from the concept of architecture viewpoints. In practice particular sets of functional models suit specific domains of system use (in some domains these are virtually de-facto standards for describing system architecture), and a by-product of this programme of work should be a better understanding of this factor with regard to blended learning systems.

Timing	Delivery Mode	
	Face-to-face with staff	Electronic delivery
Synchronised to academic calendar	Assessment feedback	Lecture notes Assignment information
Synchronised to project plans	Supervisor monitoring, Project team meetings	Review Guidance, Inter-project exchanges
Asynchronous, event driven	Design/progress reviews	Teaming tuition Role profiles Review presentation guidance
Asynchronous, on demand	Critical decisions, Authorisations, Health and safety issues, Mentoring	Previous lecture refresh and contextualisation, On-line method/tool training, Wikis/message boards

**Figure 9:** Model of Delivery Timing and Delivery Mode

## **Synthesising the architecture of an implemented solution**

Dissecting a solution into manageable units of further design detail, and when implemented how these seamlessly integrate, are the guiding factors in the development of the material architecture of any system, not least a blended learning system. It is this decomposition, achieved through iteration between functional analysis and physical synthesis, and the recursive use of this interplay to resolve ever greater implementation detail, that enables tractable solutions to be devised to satisfy complex problems. It leads into the various branches of blended learning, and within them to specific technologies and techniques, properties and contributions; in combination these are the building blocks of a blended, holistic capability. Thus this design step hands on the baton, via subordinate specifications, to a variety of learning technologies, each with specialist design knowledge and experience.

In general, candidate elements of a system solution will comprise a mix of novel components (albeit within rational bounds of the existing or anticipated capability of learning technologies) and off-the-shelf components (i.e. available, re-usable learning elements) which may in turn benefit from customisation or adaptation. For this blended learning system, candidates in this latter category are available in the form of the University of Hertfordshire's StudyNet resources, and these are figuring strongly in the architecture options and trade-offs. Though self-evident, it is worth stressing that such re-use/modification of already implemented learning elements, with known strengths and weaknesses, reduces risk level and build effort.

As in most man-made systems, and certainly in a blended learning system, humans do not just appear as users of the system, but also as design elements (arguably the most complex elements) of an implemented system. Their challenging and often highly non-linear characteristics thus have to be taken account of in design; for example, lecturers, supervisors and assessors with their respective skills, availabilities, motivations, aptitudes and other qualities that will impact system effectiveness. Again, helpfully, ISO has published standards on how to handle these issues as part of a formal design approach, notably in (ISO, 2003) which is based on an activity model that corresponds to the underlying structure of (BSI, 2002). This standard has also been adopted to provide guidance to the various implementers.

Solution constraints are an ever-present fact of system design. A dominating constraint imposed by a key stakeholder – the Academic Approvals Board – is the lead time of the approval process for any teaching module (and this relates to national academic qualification and professional body stakeholder requirements). Also, on the practical side, each new element of the learning system leads to individual implementation and integration schedules, each associated with the specification, design, integration and testing effort of individual components. Constraints of this nature mean that the sequence and timing of introduction of each element of the learning system is an important factor, and the roll out of this solution will be obliged to follow a staged sequence of introduction; one that avoids disruptive steps to users. A sequence of capability steps will lead in a managed way to the overall 'final' solution; 'final' because user feedback, changing academic environments and fresh learning technology opportunities will most probably trigger subsequent refinements.

The design of the architecture of the implemented solution has some way to run yet, but already some options are being favoured. A maxim of system design is 'think outside the boundary' – the boundary that is of an existing or previously envisaged system. The environment of operation is thus not sacrosanct and overall benefit may come from changing a presumed given. As a result, this blended learning solution looks likely to integrate a greater learning space than embarked on, i.e. to bind together subject topics (existing and new) that are acknowledged to



strongly influence the conduct of engineering projects. This suggests a re-balancing of final year modules, with an increase in academic credits for the new learning system's correspondingly greater purview and support of learning outcomes.

## Conclusions

The design principles that underlie the approach taken to create a blended learning system to support the MEng Team Projects, the practicalities that needed to be resolved and nature of the anticipated outcomes have been described. Of particular significance to the blended learning community is the use of a relevant methodology, borrowed from the industrial arena of complex systems design. Though this programme of work still has some way to run, it has highlighted the value of strong formalisation and defined process during the design, development and integration of learning opportunities. The apparent overhead of formality, requirements management, modelling and architecting is considered to be a sound investment of resources. The payback is expected to be a well-integrated, balanced whole that operates as a cohesive and compliant learning system in the eyes of its users. The careful documentation of needs, design strategy and decision making should be a foundation for evolution of this blended learning system as and when new needs and learning technology opportunities arise. Ultimately, a soundly 'engineered' solution should benefit students by providing a secure and effective framework of support and guidance for learning and self-development during their conduct of final year engineering projects.

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